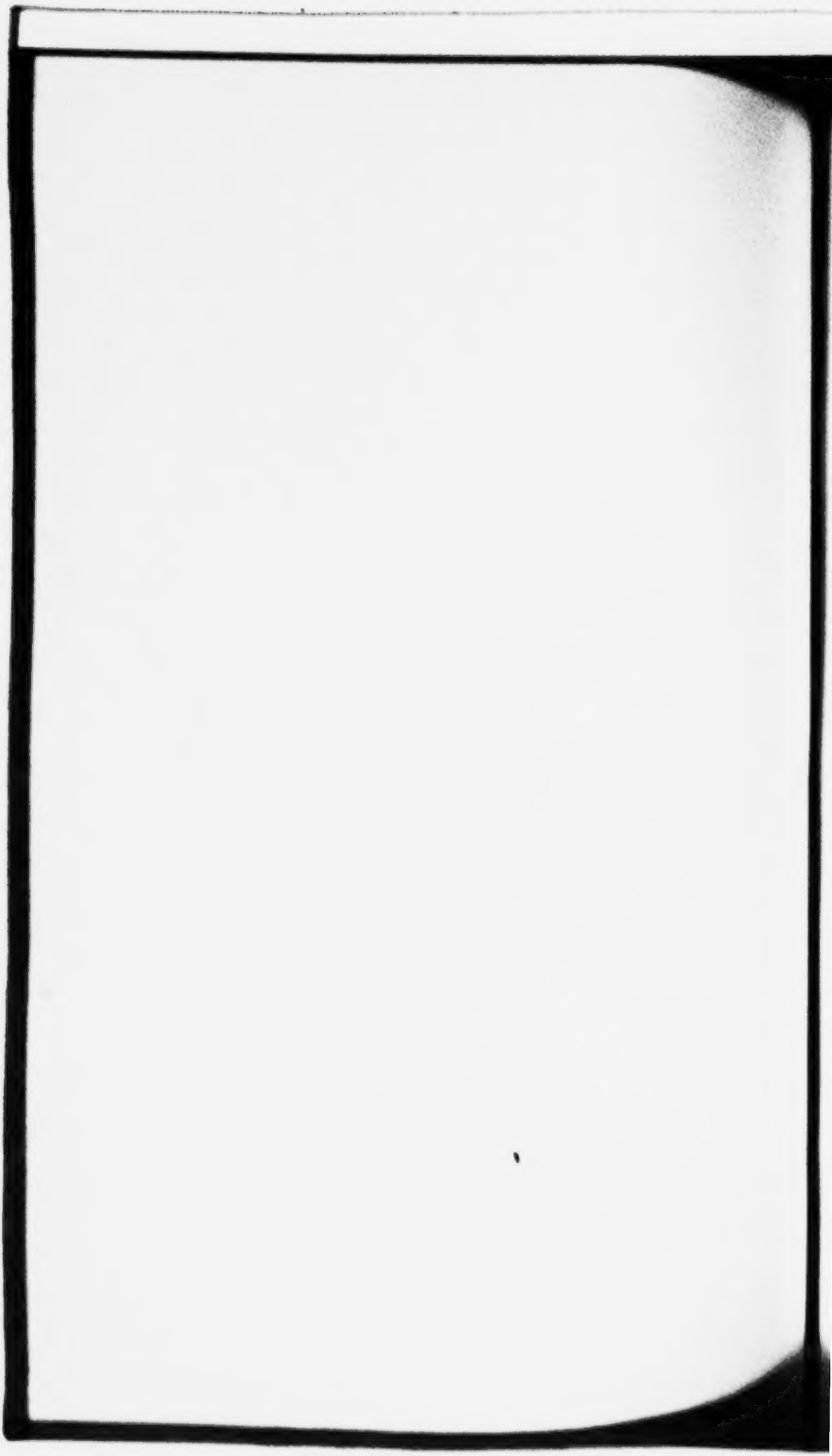

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PLAINTIFF'S EXHIBIT

Oct. 5, 1965 D. E. ISBELL 3,210,767

FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNAS

Filed May 3, 1960 2 Sheets-Sheet 1

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ELBERT A. WAGNER, JR.

Fig. 1

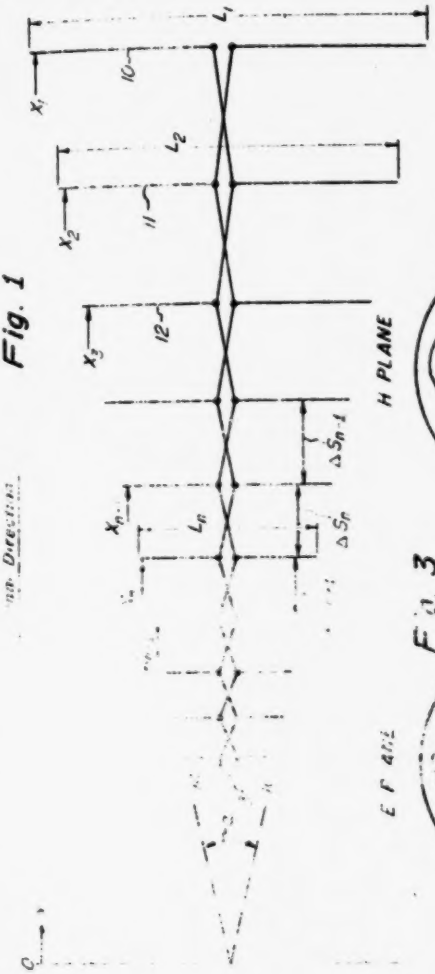


Fig. 4

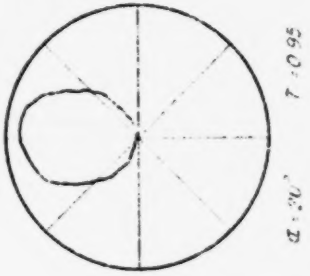


Fig. 3

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UNITED STATES DISTRICT COURT

Oct. 5, 1965 400 D. E. ISBELL 3,210,

FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNAS

Filed May 3, 1960 2 Sheets-Sheet 2

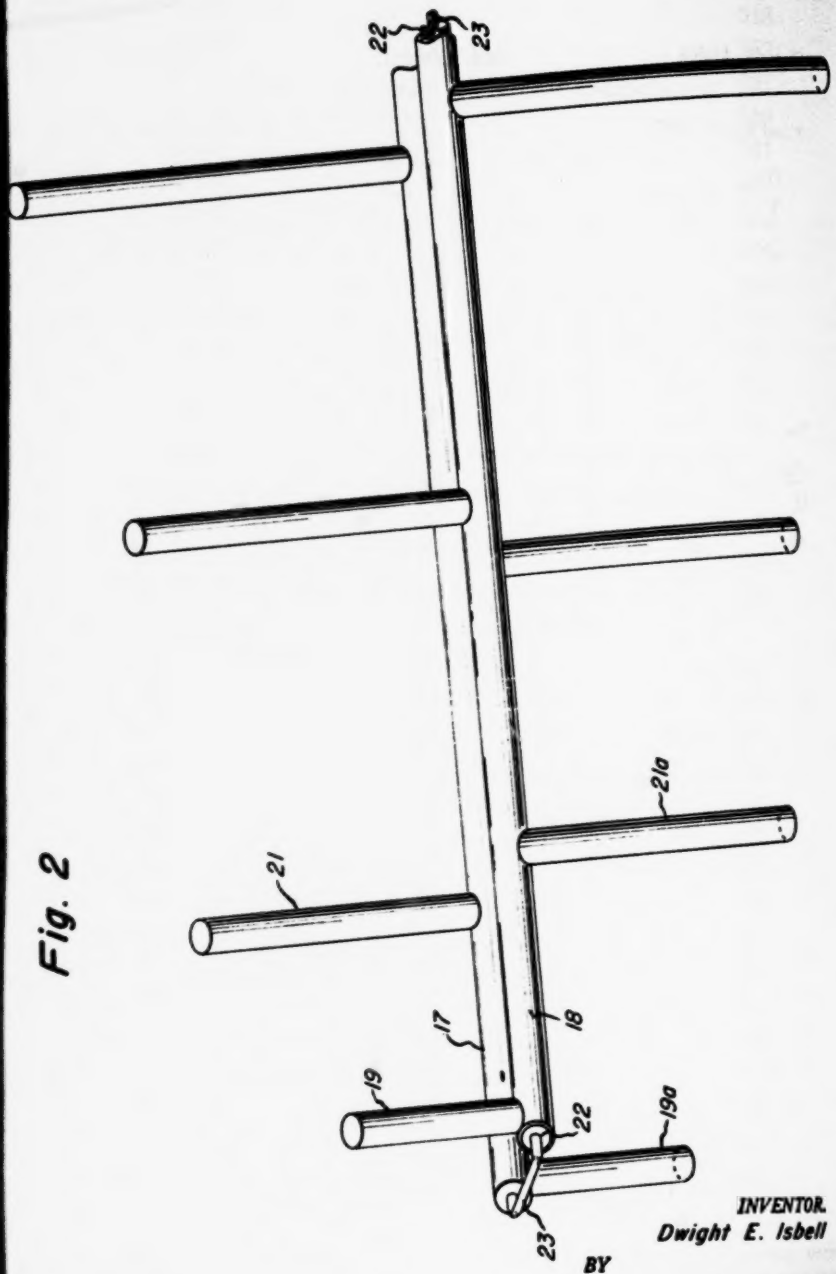


Fig. 2

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United States Patent Office 3,210,767
Patented Oct. 5, 1965

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3,210,767

# FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNAS

Dwight E. Isbell, Seattle, Wash., assignor to The University of Illinois Foundation, a non-profit corporation of Illinois

Filed May 3, 1960, Ser. No. 26,589
15 Claims. (Cl. 343—792.5)

This invention relates to antennas, and more particularly, it relates to antennas having unidirectional radiation patterns that are essentially independent of frequency over wide bandwidths.

The antennas of the invention are coplanar dipole arrays consisting of a number of dipoles arranged in side-by-side relationship in a plane, the length and the spacing between successive dipoles varying according to a definite mathematical formula, each of the dipoles being fed by a common feeder which introduces a phase reversal of 180° between connections to successive dipoles. The antennas of the invention provide unidirectional radiation patterns of constant beamwidth and nearly constant input impedances over any desired bandwidth.

The invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying drawing, in which:

FIGURE 1 is a schematic plan view of an antenna made in accordance with the principles of the invention;

FIGURE 2 is an isometric view of a practical antenna embodying the invention; and

FIGURES 3 and 4 are radiation patterns of a typical antenna, in the E plane and H plane, respectively.

Referring to FIGURE 1, it will be seen that the antenna of the invention was composed of a plurality of dipoles 10, 11, 12, etc., which are coplanar and in parallel, side-by-side relationship. It will be noted that the lengths of the successive dipoles and the spacing between these dipoles is such that the ends of the dipoles fall on a pair of straight lines which intersect and form an angle $\alpha$. In the preferred embodiment the antenna is symmetrical about a line passing through the midpoints of the dipoles, as shown.

The antenna is fed at its narrow end from a conventional source of energy, depicted in FIGURE 1 by alternator 13, by means of a balanced feeder line consisting of conductors 14 and 16. It will be seen that the feeder lines 14 and 16 are alternated between connections to consecutive dipoles, thereby producing a phase reversal between such connections.

The lengths of the dipoles and the spacing between dipoles are related by a constant scale factor $\tau$ defined by the following equations:

$$\tau = \frac{L_{(n+1)}}{L_n} = \frac{\Delta S_{(n+1)}}{\Delta S_n}$$

where $\tau$ is a constant having a value less than 1, $L_n$ is the length of any intermediate dipole in the array, $L_{(n+1)}$ is the length of the adjacent smaller dipole, $\Delta S_n$ is the spacing between the dipole having the length $L_n$ and the adjacent larger dipole, and $\Delta S_{(n+1)}$ is the spacing between the dipole having the length $L_n$ and the adjacent smaller dipole.

It will be seen from the geometry of the antennas, as given above, that the distance from the base line 0 at the vertex of the angle $\alpha$ to the dipoles forming the array are defined by the equation:

$$\tau = \frac{X_{(n+1)}}{X_n}$$

where $X_n$ is the distance from the base line 0 to the dipole having the length $L_n$, $X_{(n+1)}$ is the corresponding distance

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from the base line to the adjacent smaller dipole, and $\tau$ has the significance previously given.

The radiation pattern of the antennas of the invention, having the geometrical relationship among the several parts as defined above, is unidirectional in the negative X direction, i.e., extending to the left from the narrow end of the antenna of FIGURE 1.

The construction of an actual antenna made in accordance with the invention is shown in FIGURE 2. In this antenna the balanced line consists of two closely-spaced and parallel electrically conducting small diameter tubes 17 and 18 to which are attached the dipoles, each of which consists of two individual dipole elements, e.g., 19 and 19*a*, 21 and 21*a*, etc. It will be noted that each of the two elements making up one dipole is connected to a different one of said conductors 17 and 18, in a direction perpendicular to the plane determined by said conductors 17 and 18. Moreover, considering either one of the conductors 17 and 18, consecutive dipole elements along the length thereof extend in opposite directions. It will be seen that this construction has the effect of alternating the phase of the connection between successive dipoles, as depicted schematically in FIGURE 1. Although the dipoles of FIGURE 2 are not precisely coplanar, differing therefrom by the distance between the parallel conductors, in practice this distance is very small so that the dipole elements are substantially coplanar and the advantages of the invention are maintained. The antenna of FIGURE 2 may be conveniently fed by means of a coaxial cable 22 positioned within conductor 18, the central conductor 23 thereof extending to and making electrical connection with conductor 17 as shown.

As an example of the invention, an antenna of the type shown in FIGURE 2 was constructed using 0.125 inch diameter tubing for the balanced line and 0.050 inch diameter wire for the elements. The elements were attached to the feeder line with soft solder, and the array was fed with miniature coaxial cable inserted through one of the balanced line conductors. The antenna was defined by the parameters $\tau$=0.95 and $\alpha$=20°. The antenna had a total of 15 dipoles, with the longest dipole element being 2½" long, while the shortest element was one-half of this length, or 1¼". The array was 7½" long.

Typical radiation patterns for the above-described antenna in the E plane and the H plane are shown in FIGURES 3 and 4, respectively. These patterns were found to remain essentially constant over the band of about 1100 to 1800 mc./sec. The minimum front-to-back ratio over this band was 17 db and the directivity over the range from about 1130 to 1750 mc./sec. was better than 9 db over isotropic.

The performance of the above-described antenna clearly indicates that the antennas of the invention provide excellent rotatable beams for use particularly in the HF to UHF spectrum. In comparison to the well-known parasitic types of antennas which bear some resemblance to those of the invention, such as the Yagi array, the antennas of the invention provide a much wider bandwidth with essentially comparable directivity. Advantageously, however, the antennas of the invention need no adjusting for their performance over a wide bandwidth, compared to the parasitic types which must be adjusted by cut-and-try procedures for each frequency. Further experimental work with other antennas similar to that described above has indicated that the preferred values for the parameters which define the antennas of the invention include a range of values for angle $\alpha$ between about 20° and 100°, with $\tau$ having a value between about 0.8 and about 0.95. When these parameters have values within the preferred ranges the antennas were

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found to have essentially frequency independent performance over any desired bandwidth. The upper and lower limits of the bandwidths may be adjusted as desired by fixing the lengths of the longest dipole and the shortest dipole, respectively. It has been determined experimentally that the longest dipole element should be approximately 0.47 wavelength long at the lower limit and the shortest element should be about 0.38 wavelength long at the upper limit. Moreover, in order to provide a suitable front-to-back ratio at the low frequency limit, there should be at least 3 dipoles in the array and preferably about 10 to 30 dipoles.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A broadband unidirectional antenna comprising an array of substantially coplanar and parallel dipoles of progressively increasing length and spacing in side-by-side relationship, the ratio of the lengths of any two adjacent dipoles being given by the formula

$$\frac{L_{(n+1)}}{L_n}=\tau$$

where $L_n$ is the length of any intermediate dipole in the array, $L_{(n+1)}$ is the length of the adjacent smaller dipole and $\tau$ is a constant having a value less than 1, the spacing between said dipoles being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the dipole having the length $L_n$ and the adjacent larger dipole, $\Delta S_{(n+1)}$ is the spacing between the dipole having the length $L_n$ and the adjacent smaller dipole, and $\tau$ has the significance previously assigned, said dipoles being fed in series by a common feeder which alternates in phase between successive dipoles.

2. The array of claim 1 which is symmetrical about a line passing through the midpoint of each dipole in the array.

3. A broadband unidirectional antenna comprising an array of a plurality of substantially coplanar and parallel dipoles of progressively increasing length in side-by-side relationship, the ends of said dipoles falling on a V-shaped line forming an angle $\alpha$ at its vertex, the ratio of the lengths of any pair of adjacent dipoles being given by the formula

$$\frac{L_{(n+1)}}{L_n}=\tau$$

where $L_n$ is the length of the longer dipole of the pair, $L_{(n+1)}$ is the length of the shorter dipole, and $\tau$ is a constant having a value less than 1, the dipoles in said array being fed in series by a common feeder which alternates 180° in phase between successive dipoles.

4. The antenna of claim 3 in which the angle $\alpha$ has a value between about 20° and 100° and the constant $\tau$ has a value between about 0.8 and 0.95.

5. The antenna of claim 3 in which said feeder is a balanced line which twists 180° between the connections to successive dipoles.

6. A broadband unidirectional antenna comprising a balanced feeder line consisting of two closely spaced, straight and parallel conductors, a plurality of dipoles each consisting of two dipole elements, one of which elements is connected to one of said conductors, the other element being connected directly opposite the first to the other of said conductors, the elements of any dipole extending in opposite directions perpendicular to the plane determined by said conductors, consecutive dipole elements on each of said conductors extending in opposite directions, the ratio of the lengths of the elements in any two adjacent dipoles being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an element of any dipole in the antenna, $l_{(n+1)}$ is the length of an element in the adjacent smaller dipole and $\tau$ is a constant having a value less than 1, the spacing between said dipoles being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the dipole having the element length $l_n$ and the adjacent larger dipole, $\Delta S_{(n+1)}$ is the spacing between the dipole having the element length $l_n$ and the adjacent smaller dipole, and $\tau$ has the significance previously assigned.

7. The antenna of claim 6 wherein $\tau$ has a value of about 0.8 to 0.95.

8. The antenna of claim 6 wherein said feeder line conductors are tubular.

9. An aerial system including at least one set of parallel dipoles spaced along and substantially perpendicular to the longitudinal axis of a two-conductor balanced feeder to which the halves of the dipoles are connected at their inner ends, said dipoles being of different electrical lengths increasing substantially logarithmically from the connected end of the feeder to the other end and the dipole feeder connections being crossed over one another between adjacent dipoles, the spacings between which also increase substantially logarithmically from said connected end to the other end.

10. An antenna system for wide-band use comprising a plurality of substantially parallel conducting dipole elements arranged in substantially collinear pairs, the opposite dipole elements of each pair constituting dipole halves, a two-conductor balanced feeder having one conductor connected to each of said elements at substantially the inner end thereof, each of said dipole halves in a pair being connected to a different feeder conductor, adjacent dipole elements being reversely connected to different conductors of the feeder, said dipole elements being selectively spaced along and substantially perpendicular to said feeder, the elements of each pair being of substantially equal length, adjacent dipole elements of different pairs differing in length with respect to each other by a substantially constant scale factor, the selective spacings between adjacent dipoles generally decreasing from one end of the feeder to the other with the greatest spacing being between the longest dipoles, and means to connect the feeder to an external circuit at substantially the location of the smallest of the dipole elements.

11. An antenna system for wide-band use comprising a plurality of substantially parallel conducting dipole elements arranged in substantially collinear pairs, the opposite dipole elements of each pair constituting dipole halves, a two-conductor balanced feeder having one conductor connected to each of said elements at substantially the inner end thereof, each of said dipole halves in a pair being connected to a different feeder conductor, adjacent dipole elements being reversely connected to different conductors of the feeder, said dipole elements being selectively spaced along and substantially perpendicular to said feeder, the elements of each pair being of substantially equal length, adjacent dipole elements of different pairs differing in length with respect to each other by a substantially constant scale factor, the selective spacings between the dipoles along the feeder differing from each other also by a substantially constant scale factor, the greatest spacing being between the longest dipoles, and means to connect the feeder to an external circuit at substantially the location of the smallest of the dipoles.

12. The aerial system of claim 11 in which said scale

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factors have values within the range from about 0.8 to about 0.95.

13. An antenna system for wide-band use comprising an array of at least three linear substantially parallel conducting dipoles, each dipole being composed of two opposite substantially collinear conducting elements, a two-conductor balanced feeder having one conductor connected to each of said elements at substantially the inner end thereof, adjacent parallel dipole elements being reversely connected to a different conductor of the feeder, the two elements of each dipole being of substantially equal length and successive elements being of lengths which differ from one dipole to the next by a substantially constant scale factor within the range from about 0.8 to about 0.95, the dipoles being spaced from each other in a generally decreasing manner in the direction of decreasing element length, and means to connect the feeder conductors to an external circuit at substantially the location of the smallest dipole elements.

14. An antenna system for wide-band use comprising a minimum of three pairs of linear substantially parallel conducting elements arranged substantially coplanarly, each pair being substantially collinear and comprising the halves of a dipole, a two-conductor feeder connected to the inner ends of said collinear pairs of elements, adjacent parallel elements being connected to different conductors of the feeder so that the halves of the dipoles connect to different conductors of the feeder and adjacent dipoles are reversely connected, the halves of each dipole being substantially the same length, adjacent dipole elements being selectively spaced from each other along the feeder, the length of the successive dipole elements along the feeder decreasing in accordance with a substantially constant scale factor, each dipole and the feeder between it and the adjacent dipole constituting a cell, the dimension of the several cells measured from the point of connection of one dipole and the feeder to the outer end of the next smaller adjacent dipole also decreasing from one cell to the next in the direction of decreasing dipole length according to a substantially constant scale factor so that the combination of cells provides a substantially uniform wide-band response, and means to connect an external circuit to the feeder elements at substantially the location of the shortest of the dipoles.

15. An antenna system for wide-band use comprising a minimum of three pairs of substantially parallel and coplanar linear conducting elements arranged in substantially collinear pairs, each pair of elements comprising the halves of a dipole, a two-conductor feeder, one conductor of which is connected to each of said elements substantially at the inner end thereof, adjacent parallel elements being connected to different conductors of the feeder so that the halves of the dipoles connect to different conductors of the feeder and adjacent dipoles are reversely connected, the halves of each dipole being substantially the same length, adjacent dipole elements being selectively spaced from each other along the feeder, the lengths of the elements decreasing from one end of the feeder to the other substantially in accordance with a substantially constant scale factor within the range from about 0.8 to 0.95, each dipole and the feeder between it and the adjacent dipole constituting a cell, the cell dimension from the inner end of one dipole to the outer end of the next smaller adjacent dipole also generally decreasing from one cell to the next in the direction from the longer to the shorter dipoles so that the combination of cells provides a substantially uniform wide-band response, and means to connect an external circuit to the feeder elements at substantially the location of the shortest of the dipoles.

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March 9, 1965 P. E. MAYES ETAL Re. 25,740

LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

Original Filed Sept. 30, 1960 2 Sheets-Sheet 1

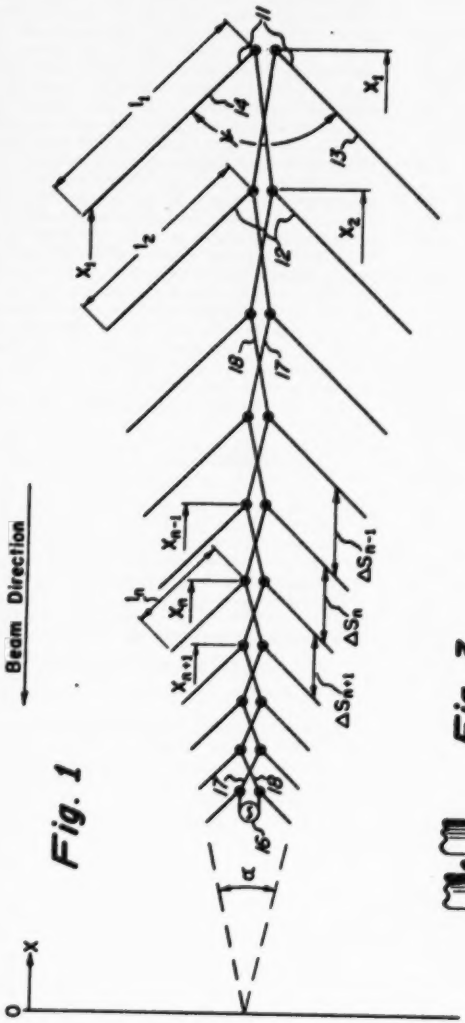


Fig. 1

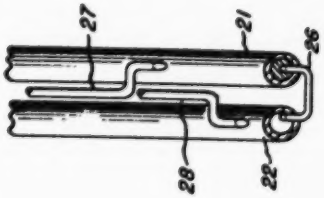


Fig. 3

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AUG 27 1963

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UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

PLAINTIFF EX. NO. 20

DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

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March 9, 1965 P. E. MAYES ETAL Re. 25,740

LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

Original Filed Sept. 30, 1960 2 Sheets-Sheet 2

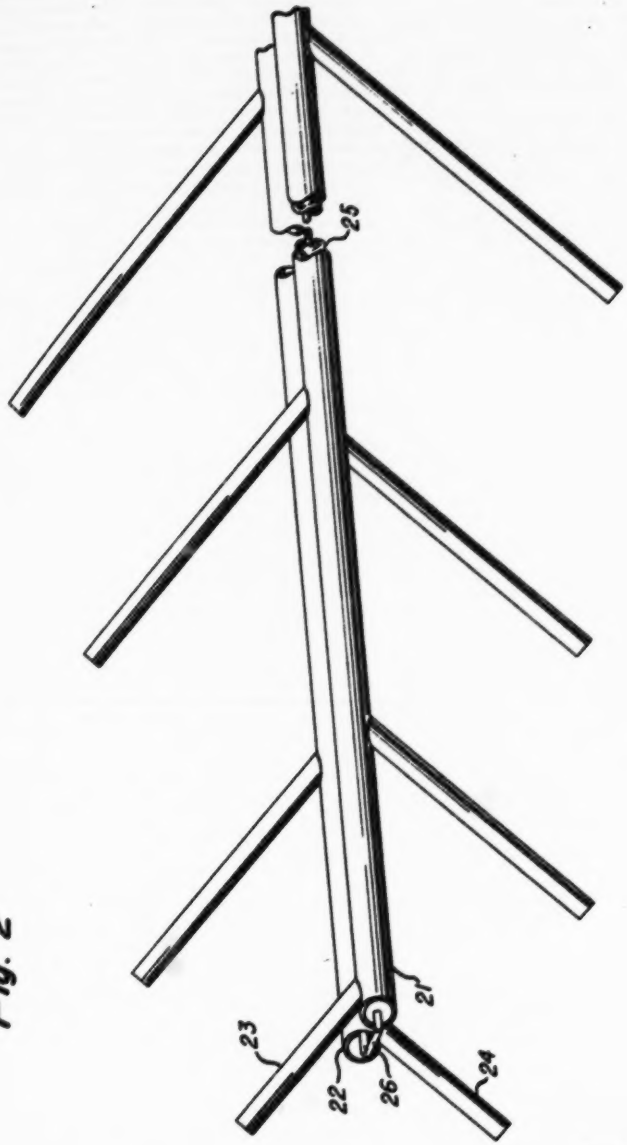


Fig. 2

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United States Patent Office

Re. 25,740
Reissued Mar. 8, 1966



# 25,740
# LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

Paul E. Mayes, Champaign, Ill., and Robert L. Carrel, Richardson, Tex., assignors to The University of Illinois Foundation, a non-profit organization of Illinois

Original No. 3,108,280, dated Oct. 22, 1963, Ser. No. 59,671, Sept. 30, 1960. Application for reissue Mar. 5, 1964, Ser. No. 363,315
17 Claims. (Cl. 343—792.5)

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

This invention relates to antennas and more particularly it relates to antennas having unidirectional radiation patterns that are essentially independent of frequency over wide bandwidths.

In the copending application of Dwight E. Isbell, Ser. No. 26,589, filed May 3, 1960, there are described certain antennas comprising coplanar dipole arrays which have an unusually wide bandwidth over which the performance of the antennas is essentially frequency independent and the input impedance nearly constant, the antennas also having a unidirectional pattern with a directivity comparable to a Yagi array. As described in the aforementioned application, these arrays comprise a number of dipoles arranged in side-by-side relationship in a plane, the length of the dipoles and the spacing between adjacent dipoles varying according to a definite mathematical formula, with each of the dipoles being fed at its midpoint by a common feeder which introduces an added phase shift of 180° between connections to successive dipoles. The dipoles which are used to make up the array vary progressively in length, the longest dipole element being about ½ wavelength long at the low frequency limit of a given antenna's effective range and the shortest element being about ¼ wavelength long at the upper frequency limit.

In accordance with the present invention, it has been found that the directivity of an antenna of the type described in the aforementioned application may be increased and the effective frequency range of an antenna of fixed size may be extended by inclining the dipoles of Isbell to form V elements, each of which consists of two straight arms of equal length defining an apex which points away from the direction of radiation of the antenna which is also the direction in which the element size decreases. The modification of the straight dipoles of Isbell to V shaped elements permits the antenna to be operated over bands of frequencies higher than those established, as described above, by the length of the shortest dipole in the antenna, with increased directivity, thus obviously increasing the effective frequency range of a given antenna.

The invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying drawings, in which the same numbers are used to denote corresponding elements in the several views and in which:

FIGURE 1 is a schematic plan view of an antenna made in accordance with the principles of the invention;

FIG. 2 is a perspective view of a practical antenna embodying the invention; and

FIGURE 3 is a fragmentary view of an improved and preferred form of an antenna similar to that shown in FIGURE 2, as seen from a point directly in front of and above the narrow end of the antenna.

Referring to FIGURE 1, it will be seen that the antennas of the invention are composed of a plurality of V elements, e.g., 11 and 12, each of which consists of a



pair of arms, e.g., 13 and 14, defining an apex in the middle of the V-elements, said V-elements being arranged in a herringbonelike pattern. The arms of a given V-element are equal in length and corresponding arms of the several V-elements, i.e., the arms on the same side of a line passing through the apexes of the V-elements, are substantially parallel to each other. It will be noted that the lengths of the arms of successive V-elements and the spacing between the apexes of the elements are such that the extremities of the elements fall on a pair of straight lines which intersect to form an angle $\alpha$. In the preferred embodiment of the invention the antenna is symmetrical about a line passing through the apexes of the V-elements, as shown.

The antenna is fed at its narrow end from a conventional source of energy, depicted in FIGURE 1 by alternator 16, by means of a balanced feeder line consisting of conductors 17 and 18. It will be seen that the feeder lines 17 and 18 are alternated between connections to consecutive V-elements, thereby producing a phase reversal between such connections.

The length of the arms in the antenna, and the spacing between the V-elements, are related by a constant scale factor $\tau$ defined by the following equations:

$$\tau=\frac{l_{(n+1)}}{l_n}=\frac{\Delta S_{(n+1)}}{\Delta S_n}$$

where $\tau$ is a constant having a value less than 1, $l_n$ is the length of an arm in any intermediate V-element in the array, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element, the subscript n designating the nth arm running in an order from larger to smaller, $\Delta S_n$ is the spacing between the apex of the V-element having the arm length $l_n$ and the apex of the adjacent larger V-element, and $\Delta S_{(n+1)}$ is the spacing between the apex of the V-element having the arm length $l_n$ and the apex of the adjacent smaller V-element.

The arms of the individual V-elements forming the antenna array are inclined to point in the direction of decreasing V-element size so that the apex of each of the elements points in a direction away from the angle $\alpha$ formed by the lines passing through the extremities of the individual V-elements.

The angle formed by the arms of a V-element is designated as $\psi$. It will be seen that when the angle $\psi$ is equal to 180°, the antennas of the invention are identical with those described by Isbell in the application mentioned above. In the instant invention, however, the angle $\psi$ preferably has a value between about 50° and 150°.

It will be seen from the geometry of the invention as given above that the distances from the base line O at the vertex of the angle $\alpha$ to the apexes of the V-elements forming the array are defined by the equation:

$$\tau=\frac{X_{(n+1)}}{X_n}$$

where $X_n$ is the distance from the base line O to the apex of the V-element having the arm length $l_n$, $X_{(n+1)}$ is the corresponding distance from the base line to the apex of the adjacent smaller V-element, the $\tau$ has the significance previously given.

The radiation pattern of the antennas of the invention having the geometrical relationship among the several parts, as defined above, is unidirectional in the negative X direction, i.e., extending to the left from the narrow end of the antenna of FIGURE 1.

The use of V-elements in the antennas of the invention, rather than dipoles, increases the directivity of the invention and also permits more effective utilization of a given antenna since the same structure can be used in several frequency modes to achieve coverage of different frequency bands. In the special case of an antenna having

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straight dipoles rather than V-elements (i.e., when $\psi=180°$), the effective frequency range is that in which the low limit corresponds to that frequency in which the largest dipole in the antenna is about ½ wavelength long and the upper frequency limit to that frequency in which the smallest dipole in the antenna is about ⅜ wavelength long. In general, therefore, it may be said that the frequency range of the straight dipole array corresponds to the mode of operation in which the lengths of the dipoles in the array are about ½ wavelength long. As the frequency is raised above the upper limit of the ½ wavelength mode in the dipole array, the antenna will also be found to radiate effectively at frequencies in which the dipoles are about ⅝ wavelengths long (the ⅝ wavelengths mode), ¾ wavelengths long (the ¾ wavelengths mode) and so on. At frequencies above the half-wavelength mode, however, the radiation pattern of the dipole array becomes multilobed and is, therefore, of limited usefulness. By inclining the arms of the dipole to form the V-elements of the instant invention, it has been found that a single lobe of improved directivity may be obtained as the frequency is raised from the half-wavelength mode through the intervening ranges to the ¾ wavelengths mode and beyond. For each mode of operation there exists an optimum value for the angle $\psi$, ranging from about 114° for the half-wavelength mode to about 62° for the ¾ wavelengths mode. By using a compromise value for $\psi$ within this range, however, a practical antenna can be made to achieve acceptable performance over several modes of operation, thereby increasing its effective range without increasing the number of elements therein. This result is possible since many of the elements forming the antenna array are used at more than one frequency.

The construction of an actual antenna made in accordance with the invention is shown in FIGURE 2. In this antenna the balanced line consists of two closely-spaced and parallel electrically conducting small diameter tubes 21 and 22 which also act as a mechanical support for the dipole elements and to which are attached the arms which form the V-elements of the invention. It will be noted that each of the two arms, e.g., 23 and 24, making up one V-element is connected to a different one of said conductors 21 and 22. Moreover, considering either one of the conductors 21 and 22, consecutive arms along the length thereof extend in opposite directions. It will be seen that this construction has the effect of alternating the phase of the connections between successive V-elements, as depicted schematically in FIGURE 1. Although the V-elements of FIGURE 2 are not precisely coplanar, differing therefrom by the distance between the parallel conductors 21 and 22, in practice this distance is usually small so that the arms of the V-elements are substantially coplanar and the advantages of the invention are maintained. In some instances, however, it may be advantageous to bend the individual arms, e.g., 27 and 28, close to the point of attachment to the feeder line, as shown in FIGURE 3, so as to position all the arms in the same plane. The antennas of FIGURES 2 and 3 may be conveniently fed by means of a coaxial cable 25 positioned within conductor 21, the outer conductor of the cable making electrical contact with conductor 21 and the central conductor 26 of the cable extending to and making electrical connection with conductor 22, as shown.

The antennas of the invention may also be fed by a balanced two wire line which is twisted between elements to achieve the desired phase reversal. Other methods of achieving the desired phasing may be employed, e.g., transmission line loops or stubs.

As an example of the invention, an antenna of the type shown in FIGURE 3 was constructed using 0.125" diameter tubing for the balanced line and 0.050" diameter wire for the arms of the V-elements. The arms were soldered to the feeder line and the array was fed by a miniature coaxial cable inserted into one of the conductors of the balanced line. The antenna had 25 arms, the largest of which was 1 ft. long with the shortest being about 3½" long. The antenna was further defined by the parameters $\tau=0.95$ and $\psi=70°$. This antenna exhibited typical directivity gains ranging from 12 db over isotropic in the ⅝ wavelengths mode to 17 db in the ⅞ wavelengths mode, with essentially constant input impedance within each mode.

Except with respect to the angle of inclination of the arms of the V-elements, the parameters which define the antennas of the invention are essentially similar to those of the corresponding straight dipole arrays in which the arms extend at right angles from the feeder lines. Thus, the parameter $\tau$ preferably has a value between about 0.8 and 0.95 and the angle $\alpha$ suitably ranges between 20° and 100°. Moreover, the upper and lower limits of the bandwidth for the ½ wavelength mode of operation can be adjusted as desired by making the longest V-element correspond in length to about ½ wavelength at the lower limit and the shortest V-element to about ⅜ wavelength at the upper frequency limit.

In addition to its use as a direct radiator or receiver, the resonant-V array of the invention has several advantages over other antennas currently used as primary feeds for parabolic and other reflectors. Its independence of frequency in any single mode assures constant illumination of the reflector. Moreover, the input impedance remains essentially independent of frequency so that no tuning is required as the frequency is varied.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A broadband unidirectional antenna comprising an array of a plurality of V-elements in a planar herringbonelike araringement, each of said elements having a pair of equal arms defining an apex, the apexes of said V-elements lying on a straight line, the corresponding arms of said elements progressively increasing in length and spacing, the extremities of the arms of said V-elements substantially falling on a V-shaped line forming an angle $\alpha$ at its vertex, the apexes of said V-elements pointing in a direction away from the vertex of said angle $\alpha$, the ratio of the arm lengths of any pair of adjacent V-elements being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an arm in the larger of said pair of V-elements, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element of said pair, the subscript n designating the nth arm running in an order from larger to smaller, and $\tau$ is a constant having a value less than 1, the spacing between the apexes of said V-elements being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the V-element having the arm length $l_n$ and the adjacent larger V-element, $\Delta S_{(n+1)}$ is the spacing between the V-element having the arm length $l_n$ and the adjacent smaller V-element, and $\tau$ has the significance previously assigned, said V-elements being adapted to be fed as a group from the small end of the individual V-elements fed at the apexes thereof by a common feeder which introduces an additional 180° phase shift between successive V-elements.

2. The antenna of claim 1 wherein the angle formed by the arms of any V-element at the apex thereof has a value within the range from about 50° to about 150°.

3. The antenna of claim 1 which is symmetrical about a line passing through the apex of each V-element therein, and in which the corresponding arms of the V-elements are parallel.

4. The antenna of claim 1 in which the angle $\alpha$ has a value between about 20° and 100° and the constant $\tau$ has a value between about 0.8 and 0.95.

5. A broadband unidirectional antenna comprising a balanced feeder line consisting of two closely spaced, straight and parallel conductors, a plurality of substantially coplanar V-elements, each V-element comprising a pair of arms of equal length defining an apex, one of said arms of each V-element being connected at the apex of said V-element to one of said conductors, the other of said arms being connected directly opposite the first to the other of said conductors, the arms of any V-element extending in opposite directions at an acute angle to the plane determined by said conductors, consecutive arms on each of said conductors extending on opposite sides of said plane, the ratio of the lengths of the arms in adjacent V-elements being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an arm of a V-element, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element, the subscript n designating the nth arm running in an order from larger to smaller, and $\tau$ is a constant having a value less than 1, the spacing of the apexes of the V-elements along said feeder line being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the V-element having the arm length $l_n$ and the adjacent larger V-element, $\Delta S_{(n+1)}$ is the spacing between the V-element having the arm length $l_n$ and the adjacent smaller V-element, and $\tau$ has the significance previously assigned.

6. The antenna of claim 5 in which the angle formed by said arms with the plane determined by said feeder line, measured in a plane perpendicular to said plane, has a value between about 25° and about 75°.

7. The antenna of claim 5 in which $\tau$ has a value of about 0.8 to 0.95.

8. An aerial system for wide-band use comprising a plurality of herringbone-like conducting V-elements planarly arranged, a two-conductor balanced feeder connected to each of said elements at substantially the inner end thereof, each two opposite V-elements forming a pair constituting dipole halves, the connection from each adjacent dipole section being to a different feeder, said V-elements being selectively spaced from each other, each V-element of each pair having arms of substantially equal length substantially defining an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and terminating at the feeder, the said dipoles of each pair being of different electrical lengths with successive dipoles differing in electrical length with respect to each other by substantially the same scale factor, each dipole and the feeder between successive dipoles constituting a cell, and the selective spacings between adjacent dipoles decreasing from one end to the other with the greater spacing being between the longest dipoles and being such that the combination of dipole lengths and spacings provides a substantially uniform wide-band response over a plurality of frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the dipoles and the feeder being made in such a manner that the directive gain of the antenna increases as operation shifts from one band to an adjacent band of higher frequencies, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements and in the direction of the smallest of the V-elements.

9. An aerial system for wide-band use including a two-conductor balanced feeder extending in a selected plane, a plurality of herringbone-like conducting V-elements planarly arranged and spaced along the feeder, each of



the elements having a pair of arms of substantially equal length defining substantially an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and all terminating at the feeder, a connection between each of the V-elements and one of the feeders at the inner end of the elements, the two V-elements forming each pair constituting dipole halves, adjacent dipole sections being connected to different feeders, each of the pairs of dipoles being of different electrical lengths with successive dipoles differing in electrical length with respect to each other by substantially a common scale factor, each dipole and the feeder connected thereto in the region between one dipole pair and the next adjacent dipole pair constituting a cell, the spacings between the dipoles as connected to the feeders differing from each other also by substantially the same common scale factor, the scale factor being so chosen that the combination of dipole lengths and spacings providing the several cells have a substantially uniform wide-band response over several frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the feeder and the dipoles being made in such a manner that the directive gain of the antenna increases with operational shift from one band to another band of higher frequency, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements in the direction of the smallest of the V-ealements.

10. An aerial system for wide-band use including an elongated two-conductor balanced feeder, a plurality of herringbone-like conducting V-elements planarly arranged and spaced along said feeder, each of the elements having a pair of arms of equal length defining substantially an apex with the apexes of the plurality of V-elements all lying in a substantially straight line, a connection between each of the V-elements and the feeder to terminate the elements substantially at the feeder, the two V-elements forming each pair constituting dipole halves, adjacent dipole sections of the plurality being connected to different feeders and the dipoles being relativtely spaced so that the spacings between successive dipoles differ from each other by substantially a common scale factor, adjacent dipole sections having different electrical lengths, each dipole and the feeder connected between it and the adjacent dipole constituting a cell, the lengths of the dipoles increasing from end of array where spacings between adjacent dipoles is less to end of the array where adjacent dipoles are spaced the greatest distance, the spacings by the scale factor variation between adjacent dipoles being such that a combination of the various dipole lengths and spacings provides a substantially uniform wide-band response over several frequency bands bearing substantially harmonic frequency relationships to each other, the connection being made in such a manner that the directive gain of the antenna increases as the operation shifts from one band to another band of higher frequency, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements in the direction of the smallest of the V-elements.

*11. An antenna system for wide-band use comprising a plurality of at least three linear dipole elements, each dipole composed of two conducting elements planarly arranged in V-formation with the smaller angle between the axes of the elements being in the range from about 62° to 114°, all dipoles lying substantially in a common plane to form a herringbone-like pattern, a two-conductor balanced feeder connected to said elements at substantially the inner ends thereof, said ends being at substantially the apex of each V-formation dipole, the connection from each adjacent dipole section being to a different feeder and the V-formation dipoles being spaced from each other in a gradually decreasing manner from the longest to the shortest, the two elements of each V-formation dipole being of equal length and successive elements being of electrical lengths which differ from one dipole to the*

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next by a substantially constant scale factor, the apexes of all elements lying in substantially a straight line and all apexes being approximately on the axis of the feeder, and means to connect the feeder elements to an external circuit at a location which is substantially removed from the longest of the dipole elements in the direction of the smallest dipole elements.

12. An antenna adapted for use over a wide frequency spectrum comprising a multiplicity of substantially coplanarly positioned conducting elements, each element forming half of a dipole with corresponding dipole halves positioned substantially parallel to one another and the two elements of each dipole being of substantially the same length, the electrical lengths of the dipole elements of adjacent dipoles differing by a factor which is substantially the same throughout the antenna so that a progressive length change occurs between the longest and shortest elements, the electrical length of each dipole being approximately an odd multiple of a half wavelength at a frequency within the operating spectrum over which the antenna is to provide a maximum response, the dipole elements of each dipole pair being arranged in V-formation and the elements forming an angle between each other in the region of the open portion of the V-formation which is in the range between about 62° and 114°, a pair of feeder conductors for feeding each pair of dipole elements, one dipole element of each pair being connected to one feeder conductor and the other dipole element of each dipole pair being connected to the opposite feeder conductor, adjacent dipole elements of different dipole pairs being connected to opposite feeder conductors and spaced along the feeders to provide a gradual spacing variance from one end to the other whereby the directive gain of the antenna increases as its operation shifts from one frequency range where the element lengths are approximately an odd integral number of half wavelengths to the next higher frequency range where the element lengths are once more approximately an odd integral number of half wavelengths, and means to connect the feeder elements to an external circuit at a location which is substantially removed from the longest dipole elements in the direction of the shortest dipole elements.

13. An antenna adapted for operating over a wide frequency spectrum comprising a plurality of pairs of conducting linear elements forming dipoles and being so positioned that the elements of each pair are arranged in substantially V-formation and so that all pairs are substantially coplanar and all elements which form each half of the several dipoles are substantially parallel to each other, a pair of feeder conductors for establishing electrical connection between the dipole elements and an external circuit, the individual dipole elements of each pair being so connected to the feeder conductors that one dipole element connects with one conductor and the other dipole element connects with the other conductor, the connections of adjacent dipole elements of each pair being reversed so that the adjacent dipole elements are connected to opposite conductors of the feeder pair, the dipole elements of the several pairs being arranged so that the inner ends of each dipole terminate at substantially the feeder conductors and the angular separation between each dipole element in the region of the open V-formation is in the range from about 62° to about 114°, the dipole elements of each of the several pairs of V-formation dipole elements differing in electrical length progressively and uniformly from each other according to a substantially constant scale factor, the longest dipole elements connecting substantially to one end of the feeder conductors and the smallest of the dipole elements connecting substantially to the opposite end of the feeder conductors, the dipole lengths all being approximately odd multiples of a half wavelength at a frequency within the operating spectrum over which maximum response is achieved and the lengths of the progressively and uniformly changing dipole elements relative to each other being such that in the direction from the longest dipole element to the shortest dipole element the lengths change substantially in accordance with a scale factor lying within the range between 0.80 and 0.95 and the particular frequency at which the individual dipoles provide maximum response progressively changes from the lowest in the operating spectrum near the longest dipole to the highest in the spectrum near the shortest dipole, the parallelly positioned pairs of adjacent dipoles being spaced relative to each other along the feeder substantially according to a selected scale factor determined by the spacing between any two adjacent pairs of dipoles so that the assembly provides substantially log-periodic antenna properties, and means to connect an external circuit to the pair of feeder elements at a location along the feeder conductors substantially removed from the longest of the dipole elements in the direction of the shortest of the dipole elements.

14. An antenna system for wide-band use comprising a minimum of three pairs of conducting V-positioned linear elements substantially coplanarly arranged, a two-conductor balanced feeder connected to said elements at substantially the inner ends thereof, one element of each pair of linear elements being located on the opposite side of the feeder from the other element of the pair with the said elements forming a pair constituting the two halves of a dipole, adjacent elements of the dipoles being parallelly positioned and connected to a different conductor of the balanced feeder, said V-positioned elements all being selectively spaced from each other, the V-positioned elements of each dipole having substantially the same length and each V-positioned dipole substantially defining an apex with the apexes of all of the plurality of V-positioned elements lying substantially in a straight line along the balanced feeder, the smaller angle between the axes of the linear dipole elements being in the range between about 62° and 114°, the electrical length of the linear dipole elements decreasing from one end of the feeder to the other, each dipole and the feeder between adjacent dipoles constituting a cell, the dimension of the several cells measured from the point of connection of one dipole and the feeder to the outer end of the next electrically smaller adjacent dipole also decreasing from one cell to the next in the direction of decreasing dipole length according to a scale factor which is substantially the same for all pairs of adjacent cells along the feeder so that the combination of cells provides a substantially uniform wide-band response over a plurality of frequency bands, the maximum spacing between adjacent dipoles being selected so that the directive gain of the antenna increases as operation shifts from one frequency band to at least one other band of a higher frequency, and means to connect the feeder elements to an external circuit at a location which is substantially removed from the longest of the V-positioned dipole elements in the direction of the shortest of the dipole elements.

15. An antenna system for wide-band use comprising a plurality of spaced linear conducting elements all located substantially coplanarly, the conducting elements being positioned to provide a plurality of V-formation arrangements with each V-formation arrangement including two elements and the plurality providing at least three V-formations, a two-conductor balanced feeder having one conductor connected substantially to the inner end of one element of each V-formation at a point approximately at the V-apex and the other conductor connected substantially to the inner end of the second element of each V-formation also approximately at the V-apex, the elements on each side of the feeder being substantially parallelly positioned, adjacent elements on the same side of the feeder being connected to different conductors of the feeder, the elements of each V-formation dipole having substantially the same length with all V-apexes lying substantially in a straight line, the V-formation elements being spaced from each other along the balanced feeder with each

dipole and the feeder between successive dipoles constituting a cell, the electrical length of each of the adjacent dipoles decreasing from the dipoles connected to the one end of the feeder to those connected to the other end of the feeder, the cell dimension measured from the point of connection of one dipole and the feeder to the outer end of the next electrically smaller adjacent dipole also decreasing from one end of the feeder to the other in the same direction substantially according to a common scale factor, such combination of cells providing a substantially uniform wide-band response over a plurality of frequency bands, the maximum spacing between adjacent dipoles being selected so that the directive gain of the antenna increases as operation shifts from one frequency band to at least one other band of higher frequency, and means to connect the feeder elements at a region substantially removed from the longest dipole elements and in the direction of the smallest dipole elements to an external circuit.

16. An antenna system for wide-band use comprising a minimum of three pairs of linear conducting elements arranged substantially coplanarly and in V-formation with the apexes of all V-formations being in substantially a straight line, each pair of elements comprising each V-formation providing the halves of a dipole, a two-conductor feeder extending substantially along the line of the apexes of the V-formation conducting elements, the elements which provide the sides of each V-formation dipole half all being substantially parallel and there being a connection from such linear elements to the feeder from substantially the end of the element at the V-formation apex, adjacent parallel linear conducting elements being connected to different conductors of the feeder so that the halves of the dipoles connect to different conductors of the feeder and adjacent dipoles are reversely connected, the halves of the V-formation elements of each dipole being substantially the same length, adjacent dipole elements being spaced from each other along the feeder, the electrical length of the linear conducting elements providing the V-formation dipoles decreasing from one end of the feeder to the other in accordance with a selected common scale factor representing the ratio of lengths between any two adjacent dipoles, each dipole and the feeder between it and the adjacent dipole constituting a cell, the dimension of the several cells measured from the point of connection of one dipole and the feeder to the outer end of the next electrically smaller adjacent dipole also decreasing from one cell to the next in the direction of decreasing dipole length according to a scale factor which is substantially the same for all pairs of adjacent cells along the feeder so that the combination of cells provides a substantially uniform wide-band response over a plurality of selected frequency bands, and means to connect an external circuit to the feeder elements at a location which is substantially removed from the longest of the V-formation dipole elements in the direction of the shortest of the V-formation dipole elements.

17. An antenna system for wide-band use comprising a minimum of three pairs of linear conducting elements arranged substantially coplanarly and in V-formation with the apexes of all V-formation linear conducting elements being in substantially a straight line, each pair of elements comprising each V-formation providing the halves of a dipole, a two-conductor feeder extending substantially along the line of the apexes of the V-formation conducting elements, the elements which provide the sides of each V-formation dipole half all being substantially parallel and there being a connection from such linear elements to the feeder from substantially the end of the element at the V-formation apex, adjacent parallel linear conducting elements being connected to different conductors of the feeder so that the halves of the dipoles connect to different conductors of the feeder and adjacent dipoles are reversely connected, the halves of the V-formation elements of each dipole being substantially the same length, adjacent dipole elements being spaced from each other along the feeder, the electrical length of the linear conducting elements providing the V-formation dipoles decreasing from one end of the feeder to the other substantially in accordance with a selected common scale factor representing the ratio of lengths between any two adjacent dipoles, each dipole and the feeder between it and the adjacent dipole constituting a cell, the cell dimension from the inner end of one dipole to the outer end of the next electrically smaller adjacent dipole also decreasing from one cell to the next in the direction from the longer to the shorter dipoles so that the combination of cells provides a substantially uniform wide-band response over a plurality of selected frequency bands, and means to connect an external circuit to the feeder elements at a location which is substantially removed from the longest of the V-formation dipole elements in the direction of the shortest of the V-formation dipole elements.

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HERMAN KARL SAALBACH, *Primary Examiner.*

ELI LIEBERMAN, *Examiner.*

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| VERY LOW FREQUENCY (VLF) | LF | MF | HF | VHF | UHF | SHF | EHF | INFRARED | VISIBLE | ULTRAVIOLET | X-RAY | GAMMA-RAY | COSMIC-RAY |
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U.S. ALLOCATIONS (See details below)

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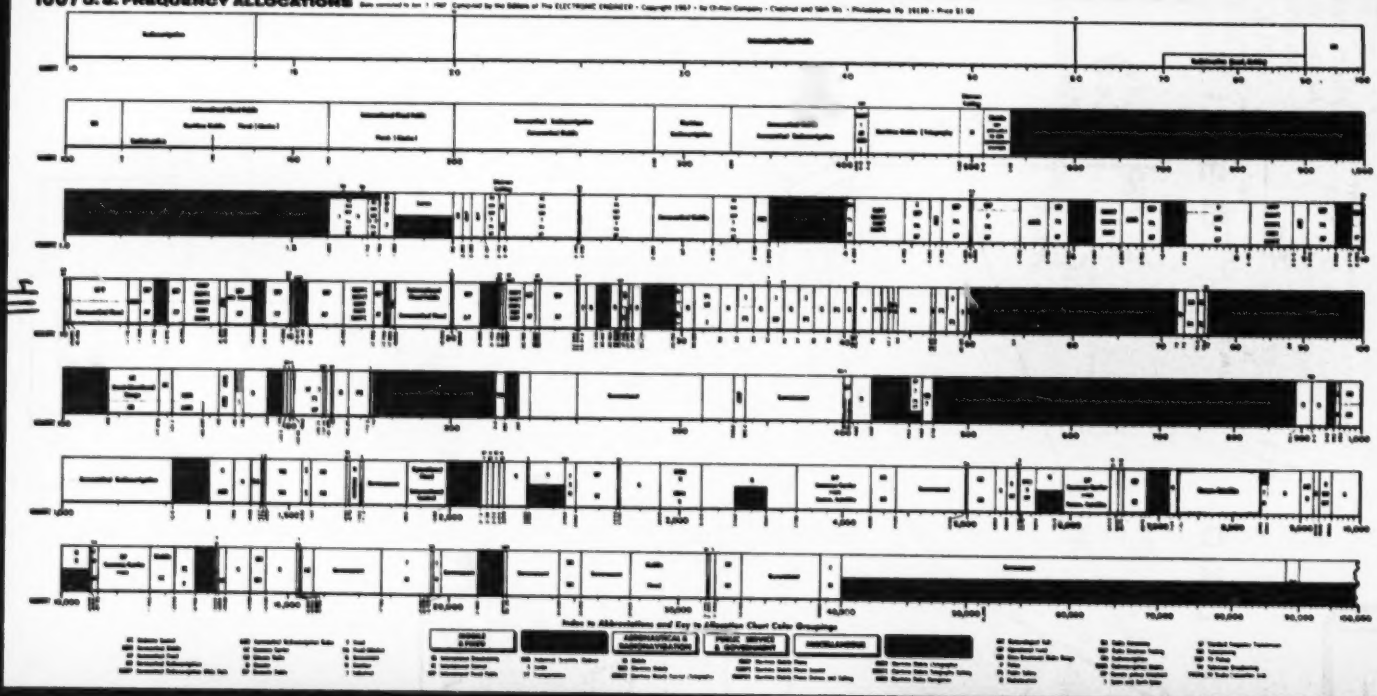


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PLAINTIFF'S EXHIBIT 29

plus industry's total resistor line

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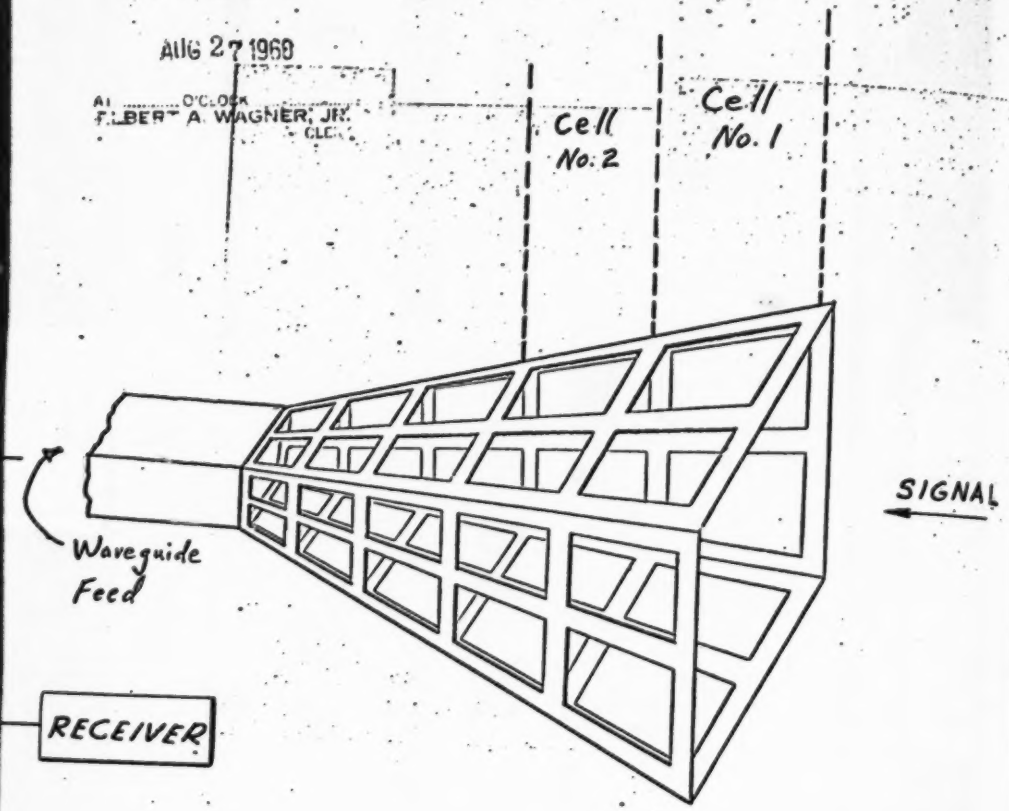

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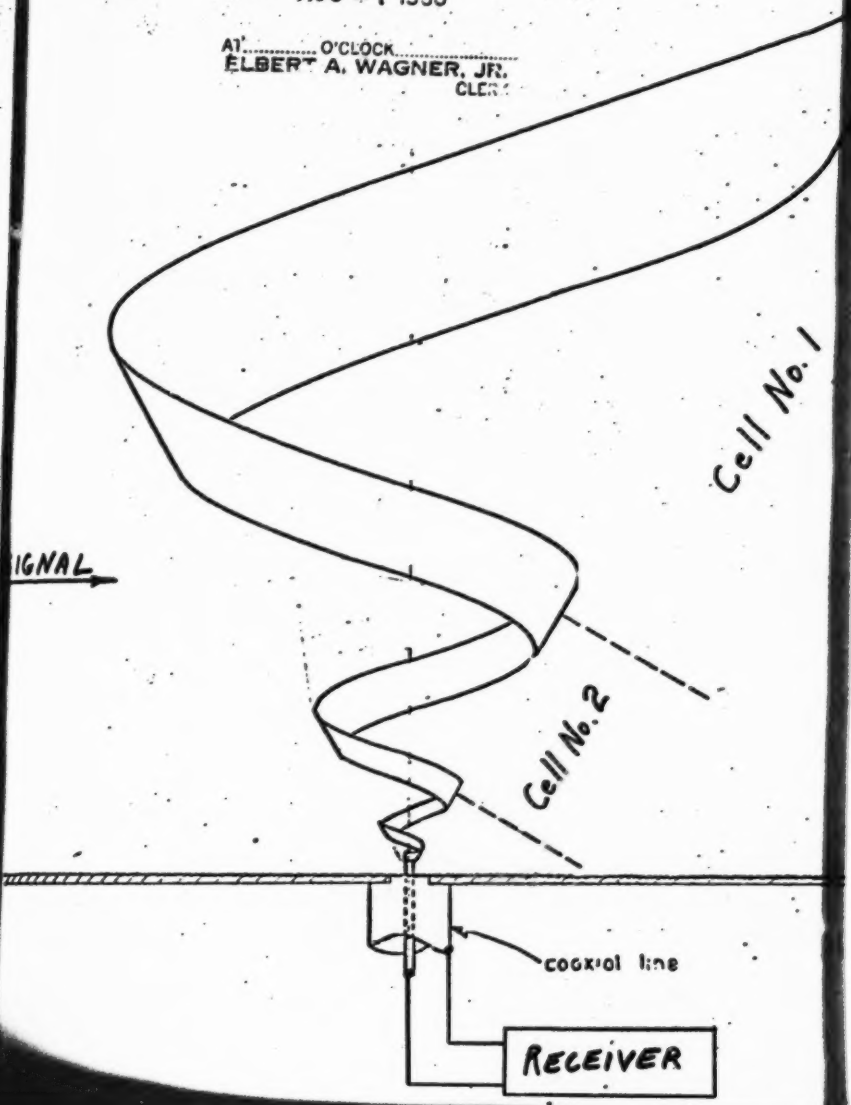

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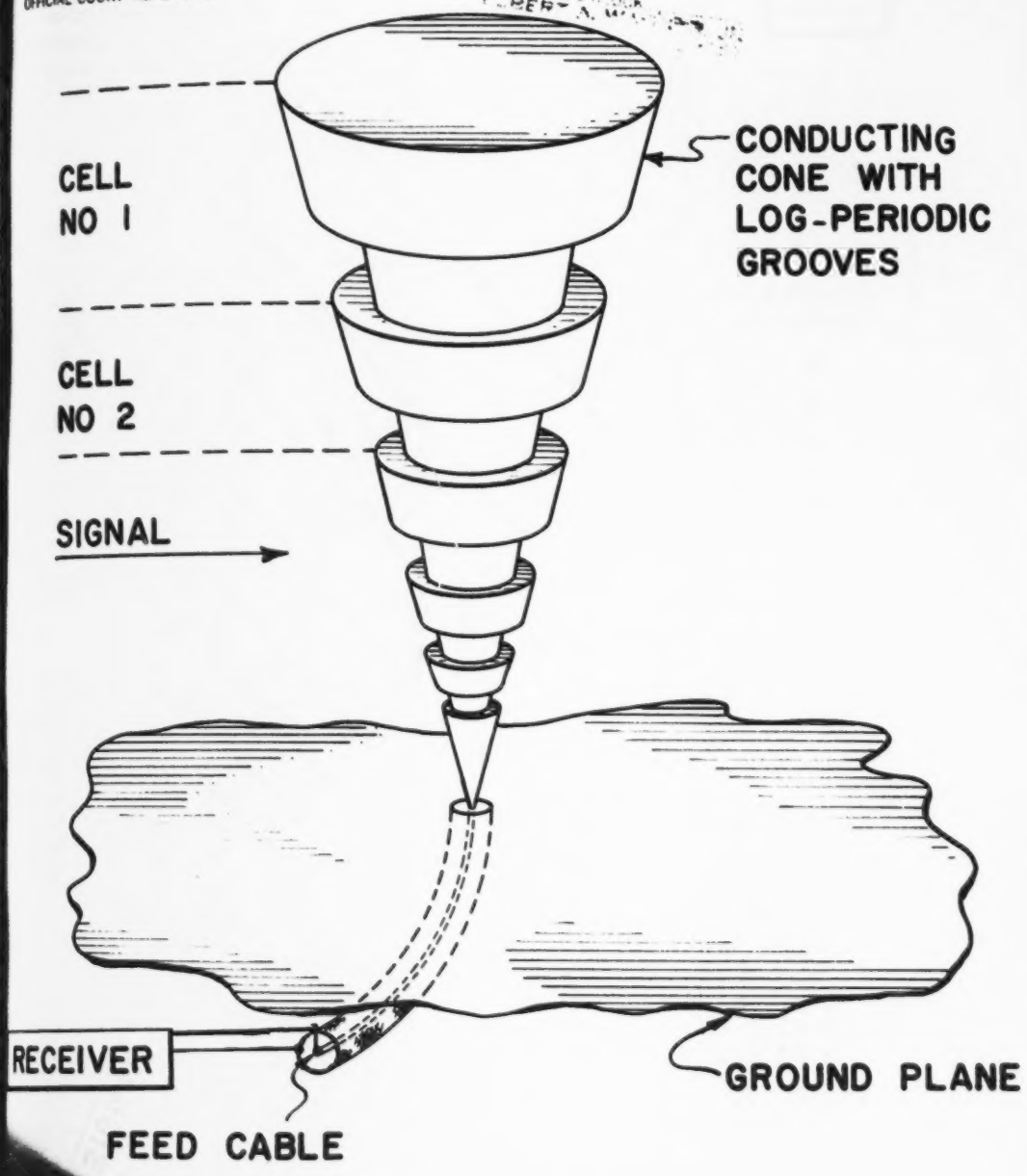

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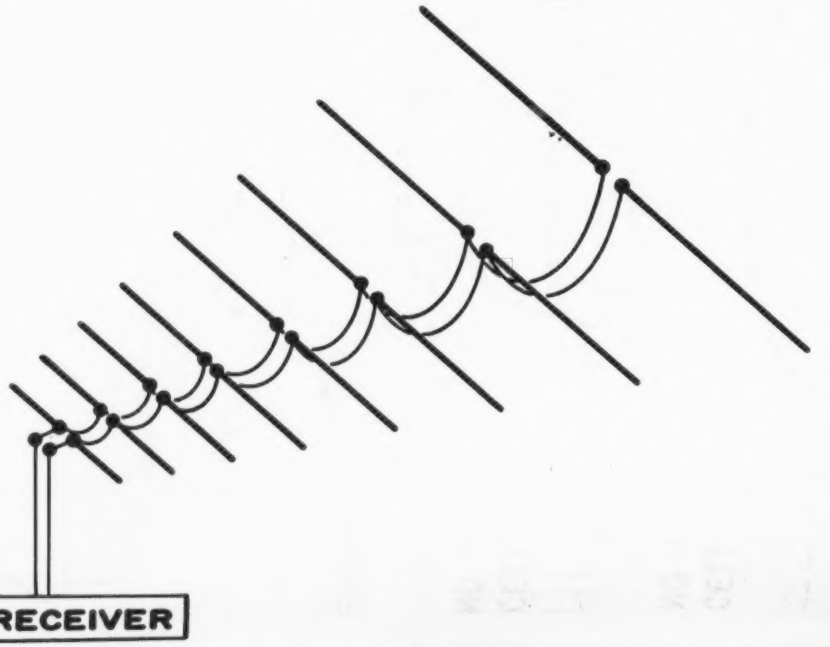


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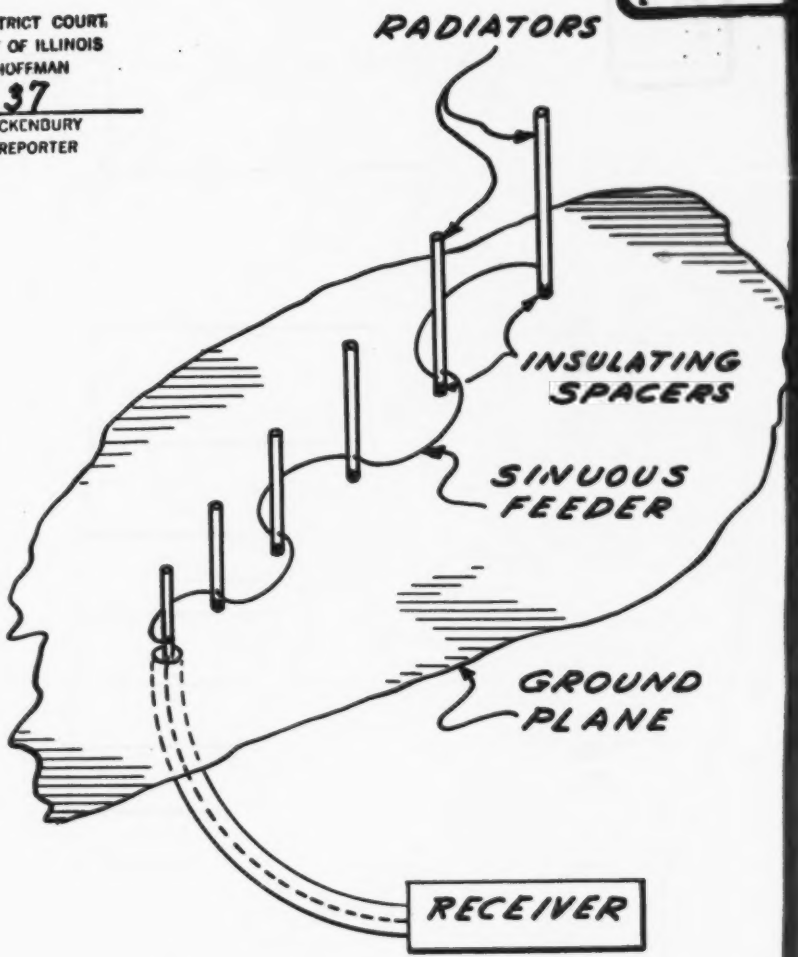


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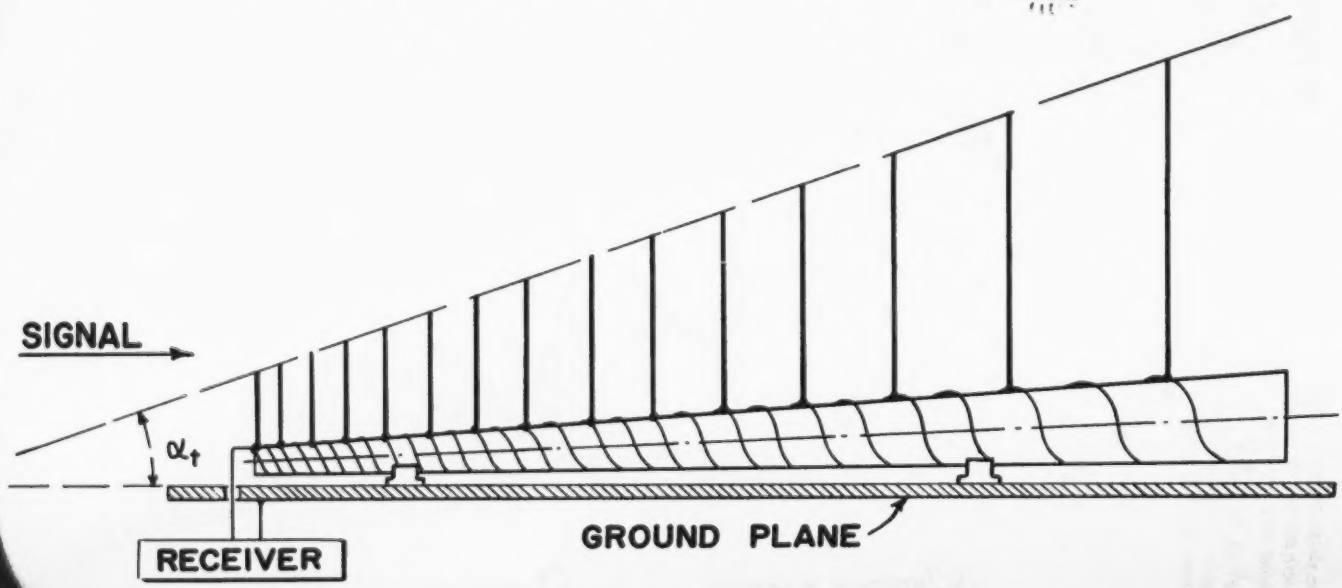


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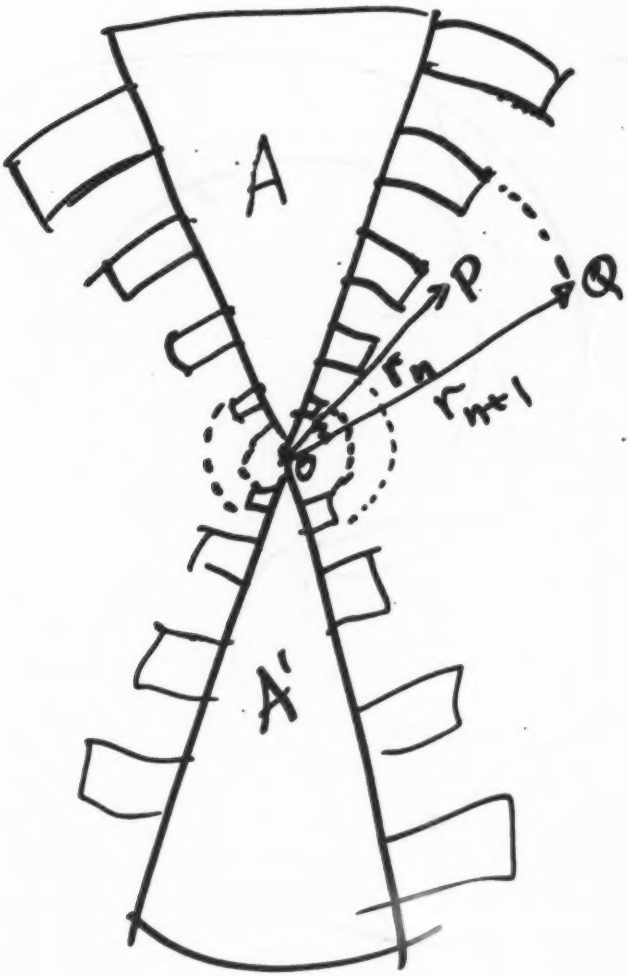
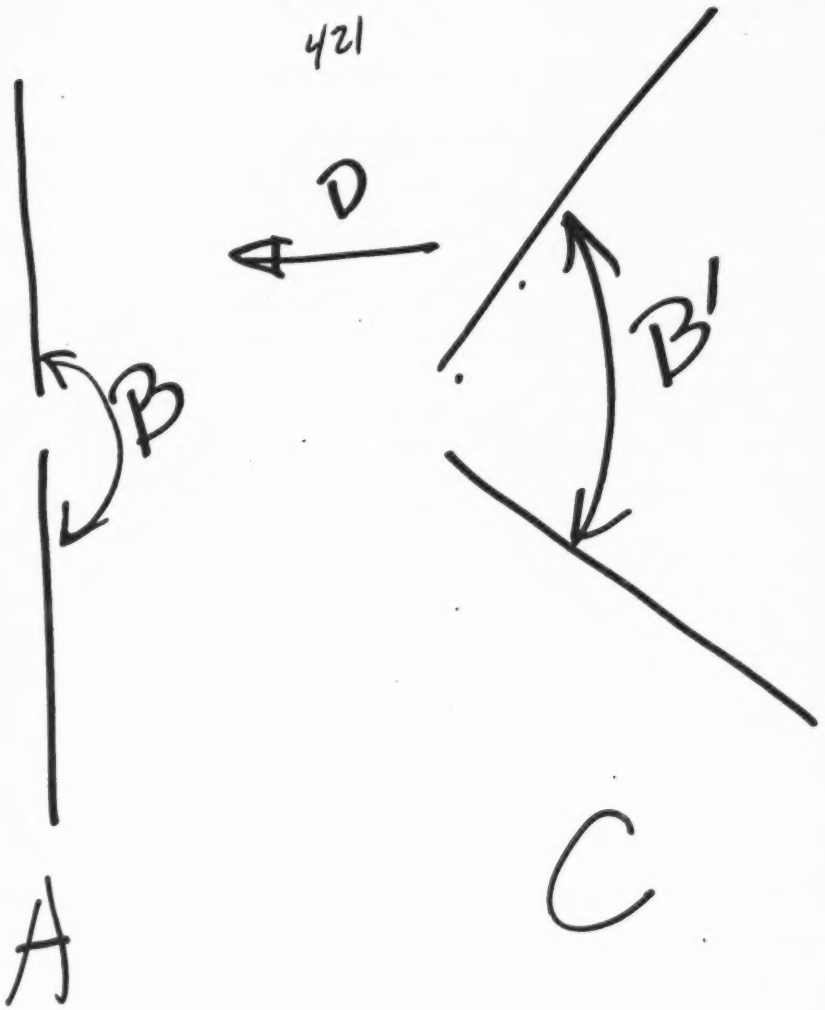
equiangular spiral




$$\tau = \frac{r_n}{r_{n+1}}$$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R. H. DU HAMEL, Manager
Electromagnetics Laboratory
Communications and Radar Division

Dr. DuHamel has had 18 years of professional experience in the fields of antennas and propagation. He originated antenna pattern synthesis methods while working in the Radar Direction Finding Laboratory of the University of Illinois from 1947 to 1951. While at RCA Laboratories from 1951 to 1952, he investigated television broadcast antenna systems. From 1952 to 1956, he was a Research Assistant Professor and Associate Director of the Antenna Laboratory at the University of Illinois. His work there included studies of surface wave launchers and antennas, aircraft antennas, microwave measurement techniques, and the original formulation and investigation of log-periodic antennas.

At Collins Radio Company, Cedar Rapids, Iowa from 1956 to 1961, he was Head of the Antenna Department and later Assistant Director of the Research Division. He was involved in the research and development of log-periodic antennas, airborne communication and navigation antennas, space vehicle antenna systems, ECM antennas, HF antenna systems and monopuls tracking feeds.

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He has been at Hughes Aircraft Company since 1961 and is now Manager of the Electromagnetics Laboratory in the Communications and Radar Division. During this time, he has been involved in basic studies of frequency-independent circuits and antennas.

Dr. DuHamel is the author of numerous technical papers and holds twelve patents (list attached). He has his B.S., M.S., and Ph.D. Degrees in Electrical Engineering from the University of Illinois. He is a Fellow of the I.E.E.E. and a member of Sigma Xi and Eta Kappa Nu.



UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

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"A Wide-Band Monopulse Antenna Using the Tapered-Line Magic-T," Fifteenth Annual Symposium, USAF Antenna Research and Development Program, Allerton Park, Monticello, Illinois, October 1965, Co-author M. E. Armstrong.

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"Log-Periodic Transmission Line Circuits - Part I: One-Port Circuits," IEEE Transactions on Microwave Theory and Techniques, June 1966, Vol. MTT-14, Number 6, pp. 264-274, Co-author M. E. Armstrong

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Patents

| DATE | PATENT NO. | TITLE | AUTHOR |
|---|---|---|---|
| 4/19/55 | 2,706,780 | Antenna Array | R. H. DuHam |
| 5/23/61 | 2,985,879 | Frequency Independent Antennas | R. H. DuHam |
| 3/28/61 | 2,977,597 | Frequency Independent Split Beam Antenna | R. H. DuHam |
| 5/16/61 | 2,984,835 | Broadside Antenna Arrays | R. H. DuHam<br>David G. Berr |
| 6/20/61 | 2,989,749 | Unidirectional Frequency-Independent Coplaner Antenna | R. H. DuHam<br>David G. Berr |
| 12/12/61 | 3,013,226 | Wide-Band Tapered Balun | R. H. DuHam<br>Vito P. Miner |
| 12/12/61 | 3,013,268 | Elliptical-Polarized Logarithmically Periodic Antenna | R. H. DuHam<br>Fred R. Ore |
| 6/26/62 | 3,041,606 | Decoupled Horizontally and Vertically Polarized Antenna | R. H. DuHam |
| 10/16/62 | 3,059,234 | Logarithmically Periodic Antenna Array | R. H. DuHam<br>David G. Berr |
| 2/26/63 | 3,079,602 | Logarithmically Periodic Rod Antenna | R. H. DuHam<br>Fred R. Ore |
| 3/31/64 | 3,127,611 | Side Loaded Logarithmically Periodic Antenna | R. H. DuHam<br>Vito P. Miner<br>Fred R. Ore |

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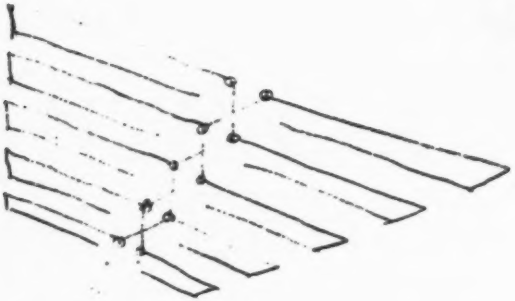

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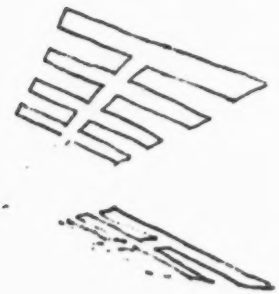

2. Symmetrical Trapezoidal Tooth Structure

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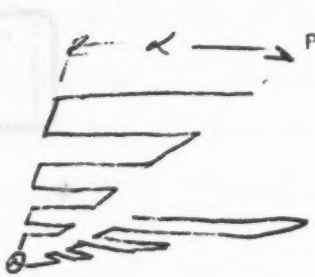

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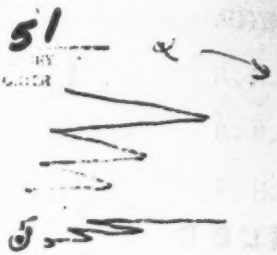

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Monopole structure

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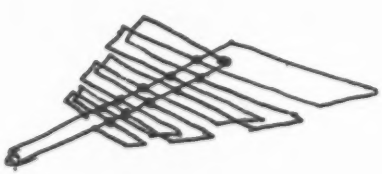

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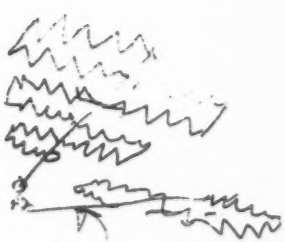

8. This same as above just rotated 180°

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# ANTENNA ENGINEERING HANDBOOK

HENRY JASIK, Editor

*Fellow, The Institute of Radio Engineers*
*President, Jasik Laboratories, Inc.*
*Westbury, Long Island, New York*

FIRST EDITION

New York Toronto London

McGRAW-HILL BOOK COMPANY, INC.

1961

# *Chapter* 18

# FREQUENCY-INDEPENDENT ANTENNAS

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## 18-2 FREQUENCY-INDEPENDENT ANTENNAS

### 18.1. BASIC PRINCIPLES

The two types of antennas described in this chapter are capable of bandwidths of operation that were believed impossible a few years ago. Both represent the development of relatively simple yet powerful ideas.

The first idea[1] evolves from the observation that the properties of an antenna, impedance and pattern, are determined by its shape and by its dimensions evaluated in wavelength. If by an arbitrary scaling the antenna is transformed into a structure equal to the original one, its properties will be independent of the frequency of operation. The antenna then satisfies the *angle condition*, which means that its form can be specified entirely by angles only and not by any particular dimension. There are two classes of antennas satisfying this condition. *Conical antennas* made up of infinite cones of arbitrary cross section having a common apex and *equiangular antennas* having their surfaces generated by equiangular spirals having a common axis and the same defining parameter.

The second idea[2] is that if a structure becomes equal to itself by a particular scaling of its dimensions, by some ratio $\tau$, it will have the same properties at a frequency $f$ and at the frequency $\tau f$. It results from this that the impedance, or any other characteristic, is a periodic function, with the period $\log \tau$, of the logarithm of frequency. The antennas obtained from this principle are called *log-periodic*. By making $\tau$ close enough to 1, the variation of the properties over the frequency band $(f, \tau f)$, and therefore everywhere, can be expected to be small. In practice, even with $\tau$ not very close to 1, good frequency-independent behaviors are observed.

To conform to the conditions stated above, equiangular as well as log-periodic structures should extend from the center of expansion 0, which is also the feed point, up to infinity. A practical antenna is obtained by taking a section of the ideal infinite structure contained between two spheres of center 0 and of radii $r_1$ and $r_2$, respectively.

Inside the smaller sphere is the feed region where the infinite structure, which ideally should converge to the point 0, is replaced by some coupling mechanism to the feed transmission line or waveguide. The length $r_1$ determines the highest frequency of operation $f_1$ of the antenna by the condition that $r_1$ must be small enough, compared with the wavelength $\lambda_1$, to make the exact shape of the coupling mechanism have little influence on the impedance or on the resulting current distribution over the antenna. Ultimately the dimension $r_1$ is fixed by the size of the waveguide or transmission line connected to the structure.

The outside dimension of the antenna, specified by the radius $r_2$, determines the lowest frequency of operation by the following considerations. It is observed, for some structures, that the currents (or the field components near to the material boundaries of the structure) decrease rapidly with the distance to the center. Thus it becomes possible to cut off the structure at the distance where these currents are so small with respect to the current $I_0$ at the feed point that they can be suppressed without changing appreciably the radiation pattern or the impedance seen at the feed point. For a given frequency the distance at which this happens is proportional to the corresponding wavelength. Thus the lower cutoff frequency may be decreased at will by increasing the size of the antenna.

The rapidity of decrease of the currents with distance depends on the particular structure considered. For conical antennas excited at the center point, the field is transverse to the radial direction and decreases only as the inverse of the distance $r$ to the center. When taking a finite portion of such an antenna, however large, the end effect will produce variations of the radiation pattern. Equiangular and some log-periodic antennas, on the other hand, exhibit a decrease of current with distance faster than $1/r$. The end effect becomes negligible at a distance, in wavelength,

depending on the exact shape of the structure. Thus some antennas will be more compact than others for a given frequency $\lambda_2$ and a given relative importance of end effect.

A property common to both types of antennas and related to the absence of end effect is that the radiation field must be substantially zero in the direction of the conductors forming the structure, seen from the center point.

For log-periodic structures another concern of importance is the variation of impedance or pattern over a period. Not all log-periodic structures are equally good from this point of view, but it is remarkable that, for some of them, very uniform performances are obtained even when the ratio $\tau$ is not close to 1.

Some relations between the two types of antennas should be noted. Equiangular antennas are special cases of log-periodic antennas with a period $\log \tau = 2\pi a$ ($a$ defined below). This property is not destroyed if the cones of revolution on which the spirals lie are distorted or given different axes. For example, one cone may be flattened, or several equiangular spiral arms with the same apex but different axes may form an array having the log-periodic property.

A class of log-periodic elements is obtained by taking a section of a solid equiangular structure by a plane passing through its axis. The structures in Figs. 18-10c and 18-10d have this property. Besides reproducing themselves by expansion in the ratio $\tau$, these structures will also reproduce by a reflection through the axis followed by an expansion in the ratio $\tau^{1/2}$. Antennas made of such elements usually exhibit smoother impedance characteristics than those that are simply log-periodic.

Although, strictly speaking, none of the finite-size antennas considered is truly frequency-independent over the range 0 to $\infty$, the name is justified because the possibilities for increasing the bandwidth are almost unlimited. Without changing the design, but simply by adding some turns to the spirals or some sections to the log-periodic antenna, any desired bandwidth can be achieved.

## 18.2. EQUIANGULAR ANTENNAS

**General Characteristics.** The structure of an antenna satisfying the angle condition must be such that if it is expanded in an arbitrary ratio $\tau$ about the feed point 0, the configuration obtained becomes congruent to the original one. Either it will coincide with the original structure, or it will coincide with a structure deduced from the original one by a rotation about some axis $D$ passing through the point 0.

The first condition is satisfied by conical structures having a common apex. Antennas obtained by taking finite sections of such structures, the discone antenna, for example, have indeed broadband properties.[3] However, they are not frequency-independent in the sense discussed in the preceding section since any finite portion, however large, will show end effects. The bandwidth therefore cannot be increased at will by increasing the size.

The other type of structure (equiangular) has been characterized by Rumsey.[1] He has shown that the following conditions must be satisfied:

1. The axis of rotation $D$ must be independent of $\tau$.
2. The angle of rotation about $D$ must be proportional to the logarithm of $\tau$.

$$\tau = e^{a\phi} \tag{18-1}$$

These equiangular structures, in contrast to the conical ones, show proper attenuation of the current with distance (with varying degree, according to the parameters of the structure) and lead to frequency-independent antennas.

**Geometry.** Using $D$ as the $z$ axis in a conventional system of spherical coordinates, the property may also be expressed by stating that the surfaces bounding the antenna

must have equations of the form

$$F(\theta, re^{-a\phi}) = 0 \tag{18-2}$$

where $F$ is an arbitrary function and $a$ is a constant.

The rotation expansion $T^\phi$ resulting from a rotation about $D$ through the angle $\phi$, followed (or preceded) by an expansion about 0, in the ratio $\tau = e^{a\phi}$, will carry the structure onto itself. (The exponential notation $T^\phi$ is justified by the obvious property

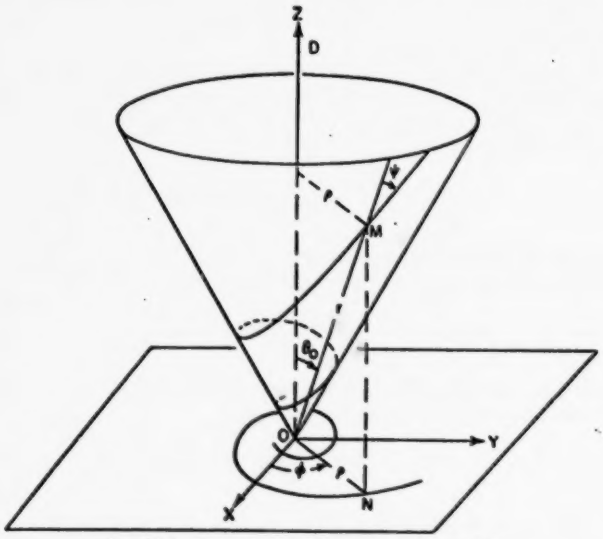



FIG. 18-1. Geometry of the equiangular spiral.

$T^\phi T^\psi = T^{\phi+\psi}$.) Starting from an arbitrary point $M$, the point $T^\phi(M)$, as $\phi$ is varied, will describe an equiangular spiral, either in the plane $z = 0$ or on a cone of revolution having $D$ as axis. All surfaces of an antenna satisfying Rumsey's condition will be generated by such spirals having a common axis and the same parameter $a$.

Figure 18-1 shows an equiangular spiral. It is drawn on a cone of revolution about $D$,

$$\theta = \theta_0 \tag{18-3}$$

and its equation is

$$r = r_0 e^{a\phi} \tag{18-4}$$

or

$$\rho = \rho_0 e^{a\phi} \tag{18-5}$$

The spiral is called equiangular because it makes a constant angle $\psi$ with the radius vector.

$$\tan \psi = \frac{\sin \theta_0}{a} \tag{18-6}$$

The arc length $s$ from the origin 0 is finite and proportional to the distance $r$.

$$s = \frac{r}{\cos \psi} \tag{18-7}$$

The projection of the spiral on the $xy$ plane is also equiangular with the same parameter $a$. In the plane $z = 0$ the equiangular spirals with the paramenter

$$a' = -\frac{1}{a} \tag{18-8}$$

are orthogonal to those with parameter $a$. On the cone $\theta = \theta_0$ the spirals of the orthogonal set have the parameter

$$a' = -\frac{\sin^2 \theta_0}{a} \tag{18-9}$$

**Pattern Rotation.** When the infinite structure is fed at the center by a constant current source of unit intensity, the electric field at frequency $f$, at some point $M$, is $\mathbf{E}(M,f)$. If the frequency is changed to $f' = f/\tau$, which amounts to a scaling $\tau$ of the dimensions, the field becomes

$$\mathbf{E}\left(M, \frac{f}{\tau}\right) = \frac{1}{\tau^2} T^{\phi} \mathbf{E}(T^{-\phi}M, f) \tag{18-10}$$

where the rotation expansion $T^{\phi}$ corresponds to $\phi = (1/a) \ln \tau$.

The radiation pattern is defined by the field on a large sphere of radius $R$.

$$\mathbf{E}(\theta,\varphi,R) = \frac{e^{-jkR}}{R} [\hat{\theta} P_{\theta}(\theta,\varphi) + \hat{\varphi} P_{\varphi}(\theta,\varphi)] \tag{18-11}$$

($\hat{\theta}$ and $\hat{\varphi}$ are unit vectors in direction of coordinates.) The relation (18-10) implies that both function $P_{\theta}$ and $P_{\varphi}$ satisfy the relation

$$P\left(\theta, \varphi, \frac{f}{\tau}\right) = P\left(\theta, \varphi - \frac{1}{a} \ln \tau, f\right) \tag{18-12}$$

*When the frequency is changed from $f$ to $f/\tau$, the pattern is rotated about $D$ through the angle* $(1/a) \ln \tau$. For finite structures this has been verified experimentally over the bandwidth of operation of the antenna.

**Practical Structures.** Simple practical structures are made of conducting wires or of metallic sheets. Although ideally the wires or the sheets should be tapered according to distance to satisfy the equiangular condition, in practice a wire of constant radius or a sheet of constant thickness may be used over moderately wide frequency bands 5:1 or 10:1).

The structures on which most data have been collected[4,5] are variants of the dipole (where the two halves have been twisted into a pair of equiangular arms) or of the slot antenna (where the edges of the slot are equiangular spirals extending from the feed point). Some multiarm structures have also been considered.

**Planar Structures.** The planar structures are made of two symmetrical equiangular arms as shown in Figs. 18-2 and 18-3.

Parameters defining the infinite structure are:

1. The rate of spiral $1/a$ which defines the expansion ratio $e^{a\phi}$ corresponding to the rotation $\phi$. It also determines the angle $\psi = \tan^{-1}(1/a)$ at which radial lines cut the spirals.

2. The arm width specified either by the angle $\delta$ or by the ratio $K = e^{-a\delta}$. When $\delta < 90°$, the structure may be considered as a slot of angular width $180° - \delta$ rather than as a dipole. Figure 18-6 gives a conversion from $a$ and $\delta$ to $K$ and to $\psi$.

The finite antenna is described by the cutoff radii $r_1$ and $r_2$ and the exact manner in which it is terminated outside of this section. If the structure is large enough to

accommodate the given frequency band, the exact shape of the termination does not matter.

The antenna may be fed by a balanced line brought into the center point along the axis. A method to be preferred, which does not disturb the field as much, consists of using a coaxial cable embedded into one arm of the spiral. Because of the rapid attenuation of the fields with distance along the spiral, no appreciable current flows in the free parts of the cable. For symmetry a dummy cable is sometimes soldered to

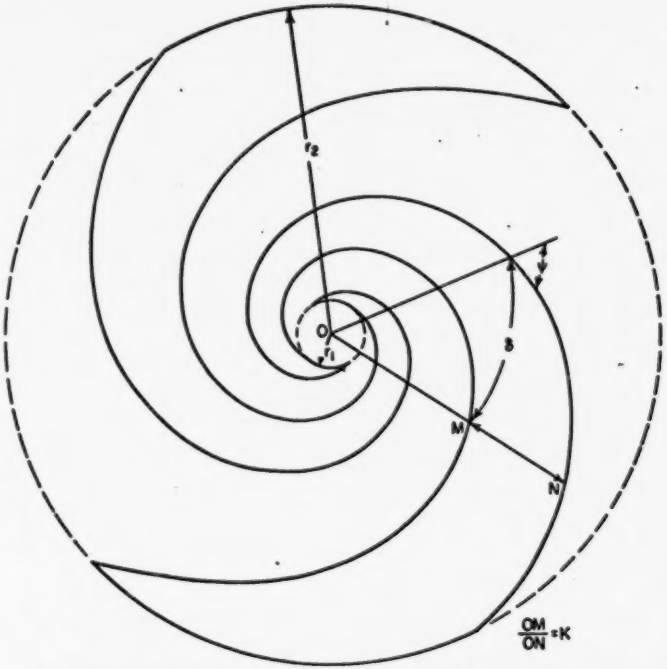



FIG. 18-2. Two-arms equiangular antenna: outline and parameters.

the other arm of the spiral in a similar configuration. Figure 18-4 shows the feed region of the antenna shown in Fig. 18-3.

The decrease of currents on the antenna, with distance to the center, appears to be approximately exponential. It is less rapid for narrow-arm or narrow-slot structures and increases with the rate of spiral $1/a$. On a wide arm the decrease is faster on the inner edge than on the outer one. The phase velocity for the currents along the antenna is close to free-space velocity at the center and increases with distance.

**Impedance.** The impedance for the infinite equiangular structure is real and independent of frequency. (If the structure has more than two terminals, this is true of the impedance matrix.)

Practical antennas differ from this ideal because they are finite and because the sheets or the wires are not tapered. In spite of this difference, standing-wave ratios close to unity may be obtained over the band of operation.

The thin two-armed symmetrical planar antennas with $\delta = 90°$ being self-complementary should have an impedance of $60\pi$ ohms. Values observed experimentally

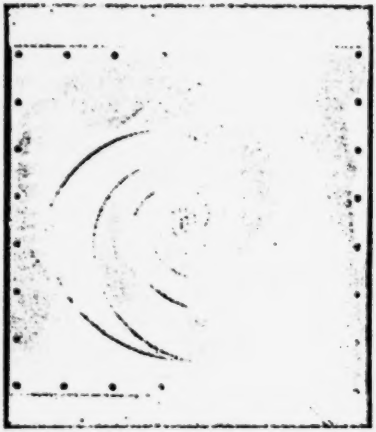


FIG. 18-3. Two-arms equiangular antenna cut in a metal plate.

FIG. 18-4. The feed region of antenna in Fig. 18-3.

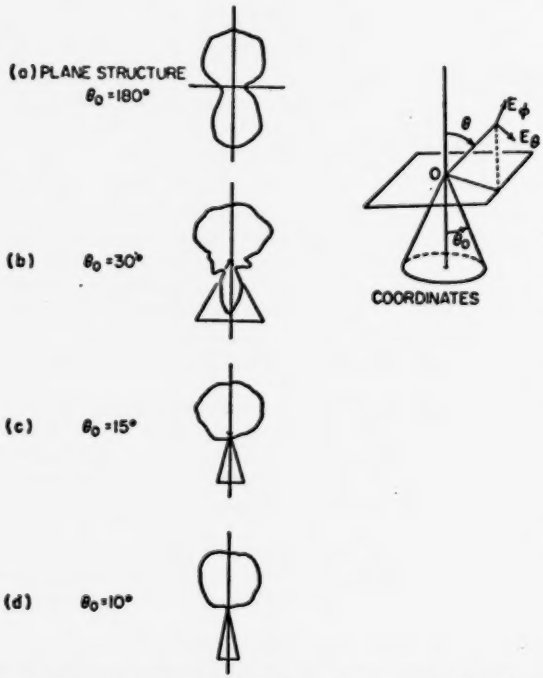



FIG. 18-5. Typical radiation patterns as a function of the cone half angle. The patterns shown are those of the $E_\phi$ field versus $\theta$. The $E_\theta$ patterns are very similar. Both are essentially independent of $\phi$. The spiral arm had a ratio $K = 0.925$ and made the angle $\psi = 73°$ with the radius vector.

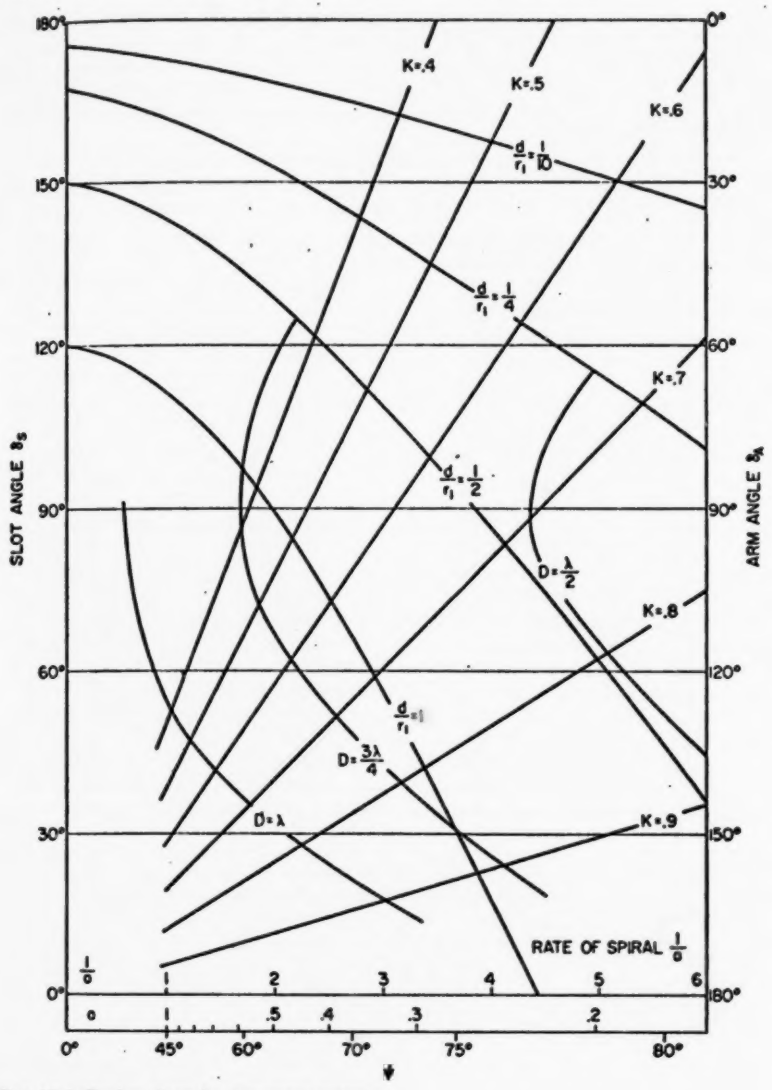



FIG. 18-6. Design chart for two-arms antenna:

- $D$ Outer diameter of structure.
- $d$ Cable diameter of minimum arm width.
- $K$ Ratio of distances from the center to the edges of the slot. (To find this ratio for an arm read the arm angle $\delta_A$ on $\delta_S$ scale.)
- $r_1$ Radius of feed region.
- $\Psi$ Constant angle between an equiangular spiral and the radius vector.

(about 120 ohms) are lower because of the presence of the cable feeding the structure. Narrow-arm structures have higher impedances.

**Radiation Pattern.** A typical radiation pattern for the planar structure is shown in Fig. 18-5a. The field is practically circularly polarized over the frequency band of operation. (The axial ratio of the field on the axis is a convenient criterion for defining the edges of the band.)

The pattern does not change much with the parameters $a$ and $\delta$ of the structure. It is more closely circular for high rate of spiral. For low rates of spiral the pattern shows asymmetry and its rotation with frequency may be observed.

FIG. 18-7. Equiangular spiral on a cone.

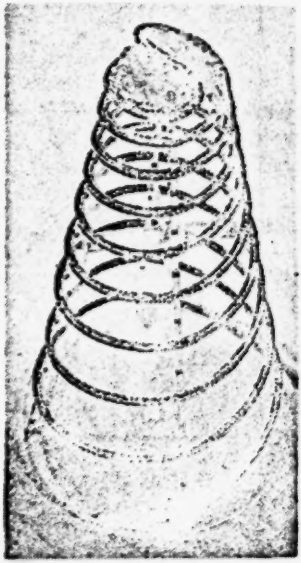


FIG. 18-8. Conical equiangular antenna made of coaxial cables.

The currents on the antenna have odd symmetry with respect to the axis $D$; the field everywhere has the same symmetry and therefore does not contain any multipole components with $e^{jm\phi}$ variation, where $m$ is even. In particular, there is no dipole moment along $D$ either electric or magnetic. The patterns obtained experimentally are fairly well represented by electric and magnetic dipoles perpendicular to $D$.

**Design Considerations.** The problem is to design an antenna of the type described above with frequency-independent behavior over a band $f_2$ to $f_1$.

The high-frequency cutoff $f_1$ being given, the radius of the feed region must be small compared with the wavelength ($r_1 \simeq \lambda_1/8$, for example). If the feed line is a coaxial cable embedded in one of the arms, the arm width at the radius $r_1$ must be at least equal to the coaxial-cable diameter $d$. Lines of constant $d/r_1$ are shown in Fig. 18-6. For a given diameter $d$ of cable and a given $r_1$, determined by $\lambda_1$, the acceptable pairs $(a,\delta)$ lie below the corresponding $d/r_1$ curve.

The low-frequency cutoff $f_2$ is linked to the attenuation along the spiral, which in turn depends on $a$ and $\delta$. The diameter of the antenna in wavelength, $2r_2/\lambda_2$, at the lower edge of the band becomes a function of $a$ and $\delta$ once the performance of the antenna at frequency $f_2$ has been specified. The curves $2r_2/\lambda_2$, labeled $D/\lambda$ on Fig. 18-6,

have been constructed using as a criterion of performance the condition that the axial ratio should be less than 2 in the direction of the axis. For other performance requirements these curves indicate only the order of magnitude of the diameter $D$.

The ratio $(r_2/r_1)/(f_1/f_2)$ = dimension ratio/frequency ratio may be taken as a figure of merit of a particular structure, indicating how compact the antenna can be made for a given bandwidth. This ratio is normally close to 1 and larger.

**Nonplanar Structures.** The balanced two-arms equiangular antenna may be wrapped on the surface of a cone of revolution as shown in Fig. 18-7. The resulting pattern becomes unidirectional, with the major lobe in the direction of the apex. It is still substantially circularly polarized over a wide portion of the pattern. The pattern is usually smoother than for the bidirectional or planar antenna. Successful antennas have been made replacing the tapered arm by a pair of spiral coaxial cables, one of them being used as the feed line as shown in Fig. 18-8. Variations of the pattern with cone angle are shown in Fig. 18-5. The design considerations discussed above apply to these structures if $a$ is replaced by $a/\sin \theta_0$.

For a sufficient rate of spiral the pattern remains circularly polarized a long way off the axis, and because of the odd symmetry of the currents, there is no dipole moment along the axis. When the antenna is rotated about the axis through some angle $\alpha$, the phase of the field in the main lobe changes also by $\alpha$. This property may be used for phasing the elements of an array.

## 18.3. LOG-PERIODIC ANTENNAS

**General Characteristics.** The geometry of log-periodic antenna structures is chosen so that the electrical properties must repeat periodically with the logarithm of the frequency. Although this appears to be a backward approach to the broadband-antenna problem, nevertheless frequency independence can be obtained when the variation of the properties over one period, and therefore all periods, is small. The log-periodic design principles are illustrated in Fig. 18-9. A metal-sheet log-periodic structure with trapezoidal teeth is shown in Fig. 18-9$a$. The two half structures are fed against each other by a generator placed between their vertices. The four sets of teeth are defined by similar curves, the equations for which may be written in polar coordinates as $\theta = g(\tau)$, where $g(\tau)$ is some function of $\tau$. If $\theta$ is plotted vs. the ln $\tau$ in rectangular coordinates, that is, $\theta = f(\ln \tau)$, then the log-periodic principles demand that $f$ be a periodic function. This is illustrated in Fig. 18-9$b$ where the two curves which define the upper half structure of Fig. 18-9$a$ are plotted vs. the ln $\tau$. Letting $\tau = R_{n+1}/R_n$, where $R_n$ is the distance from the vertex to the outer edge of the tooth, it is seen that the period of the curve is ln $(1/\tau)$. Other shapes of teeth, such as triangular or curved teeth, lead to other types of periodic curves when $\theta$ is plotted vs. logarithm of $\tau$. It may be seen that the logarithmic principle implies two conditions. The first is that all similar sets of dimensions, such as $R_1$, $R_2$, $R_3$, etc., must form a geometric sequence with the same geometric ratio $\tau$. The second is that angles are used to a considerable extent in defining the antenna. For example, the extremities of the teeth and the triangular supporting section of the teeth are defined by angles.

Now if the antenna structure of Fig. 18-9$a$ were infinitely large and infinitely precise near the feed point, it is easily reasoned that the structure must look exactly the same to the generator every time the frequency is changed by the factor $\tau$. The current distribution on the structure at $\tau f_0$ is identical with that at $f_0$ except that everything is moved out one step. Thus, since the wavelength has changed by a proportionate amount, the radiation pattern and the input impedance must be the same at $\tau f_0$ and $f_0$. This is illustrated in Fig. 18-9$c$ where the magnitude of the input impedance varies periodically with the logarithm of frequency. Because of the special left-right asymmetry of the structure of Fig. 18-9$a$ (with $r_n = \sqrt{\tau}\, R_n$), the period of the imped-

ance curve is ½ ln (1/τ) rather than ln (1/τ). The radiation pattern also exhibits a similar periodicity with frequency, but with a period equal to ln (1/τ).

If the variation of the impedance and pattern is small over a period, and therefore all periods because of the repetitive characteristics, it is seen that the result is essentially a frequency-independent antenna. Fortunately, some *finite* log-periodic structures provide frequency-independent operation above a certain low-frequency cutoff, which occurs when the longest tooth is approximately one-quarter wavelength long. Frequency-independent operation above the cutoff frequency is possible because log-periodic antennas display little end effect. It is found that the currents on the structure die off quite rapidly past the region where a quarter-wave tooth exists. This

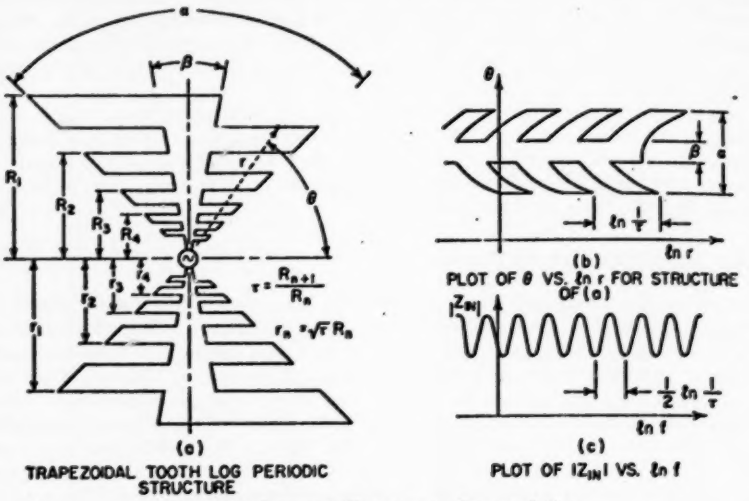



FIG. 18-9. Log-periodic antenna characteristics.

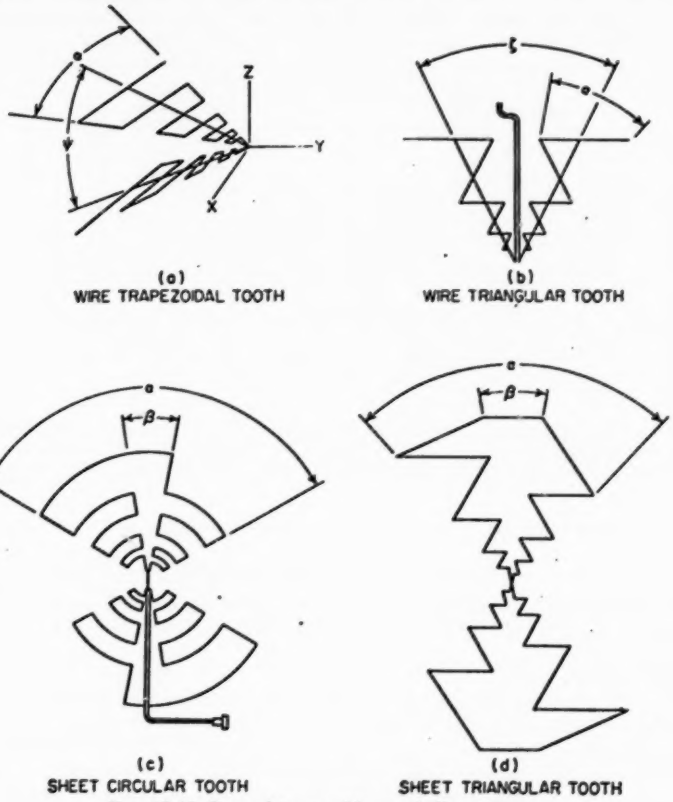
means that a smaller and smaller portion of the antenna is used as the frequency is increased, which is another way of saying that the effective electrical aperture (the aperture measured in wavelengths) is essentially independent of frequency. Since it is not possible to extend the antenna to the origin because of the presence of the feed transmission line, a high-frequency cutoff occurs when the shortest tooth is about one-quarter wavelength long.

The structure of Fig. 18-9*a* is horizontally polarized and has a bidirectional beam, with the beams pointing into and out of the paper. If the input impedance is plotted on a Smith chart over a frequency range of several periods, it will be found that the locus forms an approximate circle with the center lying on the zero reactance line. The characteristic impedance of the log-periodic structure is defined as the geometric mean of the maximum and minimum real values on the locus. The VSWR referred to this characteristic impedance is then simply equal to the ratio of the maximum impedance to the characteristic impedance.

**Practical Structures.** There is an infinite variety of log-periodic structures. A few of the successful and most practical structures[2,6,7,9] are illustrated in Fig. 18-10. Figure 18-10*a* and *b* shows wire versions of log-periodic structures with trapezoidal and triangular teeth, respectively. Figure 18-10*c* and *d* shows sheet structures with circular and triangular teeth. For all the structures shown, the angle $\alpha$ defines the

extremities of the teeth and the angle $\beta$ defines the central supporting structure. All the various structures illustrated have similar radiation pattern and impedance characteristics. The radiation is due mostly to currents flowing in the teeth, and hence the polarization is transverse to the center line of the half structure.

By orienting the two half structures at an angle $\psi$ with respect to each other, as shown in the nonplanar arrangement of Fig. 18-10*a*, a unidirectional beam pointing




(a) WIRE TRAPEZOIDAL TOOTH

(b) WIRE TRIANGULAR TOOTH

(c) SHEET CIRCULAR TOOTH

(d) SHEET TRIANGULAR TOOTH

FIG. 18-10. Several types of log-periodic antennas.

along the positive $Y$ axis is formed.[6] A unidirectional beam may also be formed with the coplanar arrangement[8] shown in Fig. 18-10*b* where the center lines of the two half structures are separated by an angle $\zeta$. For this case the beam would point down.

Theoretically, the thickness of the sheets and the diameter of the wires should increase linearly with distance from the vertex of the half structures. Practically, this is not necessary for bandwidths less than 5:1. The greater the bandwidth, the more tapering is required. Bandwidths of 20:1 are easily achieved, and bandwidths of 100:1 are feasible if the theoretical design is closely approximated.

The two half structures form a balanced antenna. It may be fed with a balanced two-wire line with wires attached to the vertices of the half structures and placed to minimize distortion of the radiation pattern. For unidirectional structures the trans-

mission line is usually brought in along the line bisecting the center lines of the two half structures as shown in Fig. 18-10*b*. The antennas may also be fed with a coaxial line which is brought in along the center line of and bonded to one half structure. A dummy cable is usually added to the other half structure to keep the antenna balanced. This type of feed forms in effect a frequency-independent balun.

A recent[9] and rather simple type of log-periodic antenna is illustrated in Fig. 18-11. It consists of an array of dipoles with lengths and spacings arranged in a log-periodic manner. The dipoles are excited by a uniform two-wire line with the line transposed between adjacent dipoles. The antenna may be fed with a balanced line connected to the feed point or a coaxial line entering from the right and passing through and inside

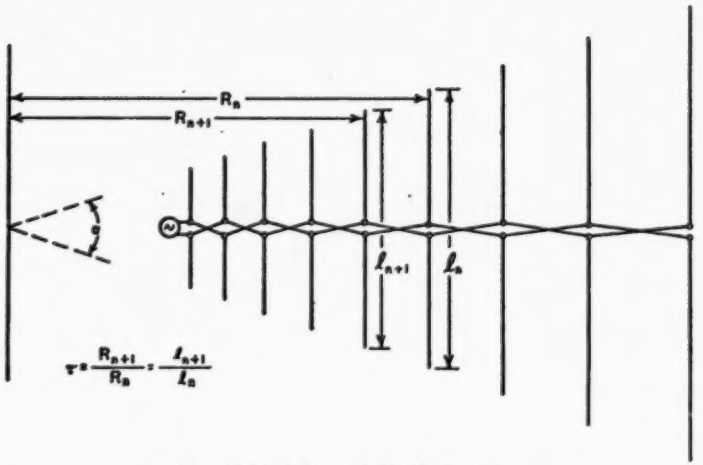



FIG. 18-11. A log-periodic dipole array.

one of the balanced lines to the feed point. It may be noticed that this antenna may be derived from that of Fig. 18-9 by letting the tooth width and the angle $\beta$ approach zero and then folding the two half structures about the horizontal axis so that the angle $\psi$ approaches zero.

All the various types of half structures described above are planar in form. The log-periodic principles can easily be generalized to include nonplanar half structures or three-dimensional structures. An example of the former is a wire trapezoidal tooth structure with the transverse wires curved so as to lie on the surface of a cone and the vertex coinciding with the vertex of the half structure. A solid biconical antenna with transverse troughs cut in the cones in a log-periodic manner is an example of a three-dimensional structure. Since these more complex structures have not proved too feasible as yet, they do not warrant further discussion.

It should be pointed out that many types of log-periodic structures are not broadband because of either extreme variation over a period or severe end effect which destroys the periodicity of the electrical characteristics. Only the successful structures are described herein. Unfortunately, it is not possible to determine a priori the frequency-independent types of log-periodic antennas.

Since log-periodic antennas are too complex to analyze by present-day theoretical methods, they must be investigated by logical experimental methods. However, their repetitive nature greatly simplifies the initial experimental investigation because the characteristics need only be measured over one or two periods of frequency. The

operation over other periods may be readily predicted. Although a large amount of experimental data has been obtained, much remains to be done.

**Self-complementary Structures.** A means for obtaining an antenna with a constant input impedance is to take a self-complementary structure, i.e., a planar structure, in which the metal area is congruent to the open area. Booker[10] has shown, using an extension of Babinet's principle, that the product of the impedances of two complementary structures equals the square of $60\pi = 189$ ohms. Therefore a self-complementary structure has an impedance of $60\pi$ ohms, independently of frequency. This does not ensure constancy of the radiation pattern, but log-periodic structures, for

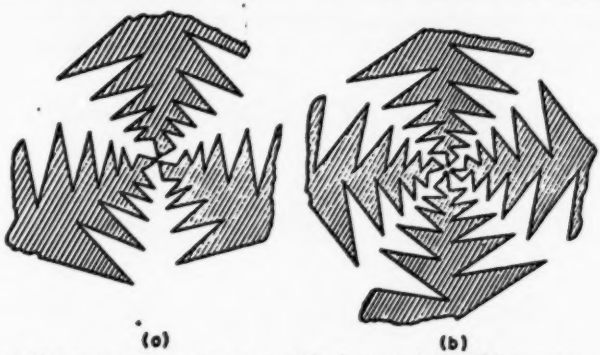



FIG. 18-12. Self-complementary structures with three- and fourfold symmetry. For (*a*) a rotation of $2\pi/3$ brings the structure onto itself while a rotation of $\pi/3$ brings it onto the complementary structure. For (*b*) rotation of $\pi/2$ and $\pi/4$, respectively, produces these results.

instance, that are also self-complementary will have a constant input impedance even over the period $f$ to $\tau f$.

Self-complementarity implies an infinite structure. However, in cases, where the end effects can be neglected, a finite portion of the ideal structure behaves almost as if it were infinite over a frequency range that may be increased at will by extending the structure.

Booker's relation applies only to two-terminal structures such as a narrow strip and the complementary slot fed at the center point. The relation has been extended[11] to the impedance matrices $Z_1$ and $Z_2$ of two complementary structures, as follows. Introducing the matrix

$$\Delta = \begin{vmatrix} 1 & -1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & -1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & -1 & \cdots & 0 \\ \cdot & \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdot & & \cdot \\ -1 & 0 & 0 & 0 & \cdots & 1 \end{vmatrix} \tag{18-13}$$

of order $n$ and its transpose $\Delta'$, the relation is

$$\Delta' Z_1 \Delta Z_2 = \eta^2/4 \tag{18-14}$$

where $\eta$ is the intrinsic impedance of the surrounding medium ($\eta \simeq 120\pi$ in air).

When an $n$-terminal antenna is self-complementary and has also $n$-fold symmetry (Fig. 18-12), it is possible, by using this relation, to compute its impedance matrix.

Introducing $\epsilon = \exp(2\pi j/n)$, the eigenvectors of the matrix $Z$ are

$$I_m = [1, \epsilon^m, \epsilon^{2m}, \ldots, \epsilon^{(n-1)m}] \tag{18-15}$$

and the corresponding eigenvalues are

$$Z_m = \frac{\eta/4}{\sin\left(\pi \frac{m}{n}\right)} \tag{18-16}$$

From this, the coefficients of the matrix $Z$ for any value of $n$ may be computed, and by straightforward circuit analysis, the impedances obtained by connecting the terminals in groups may also be deduced. A wide range of frequency-independent impedances may thus be realized.

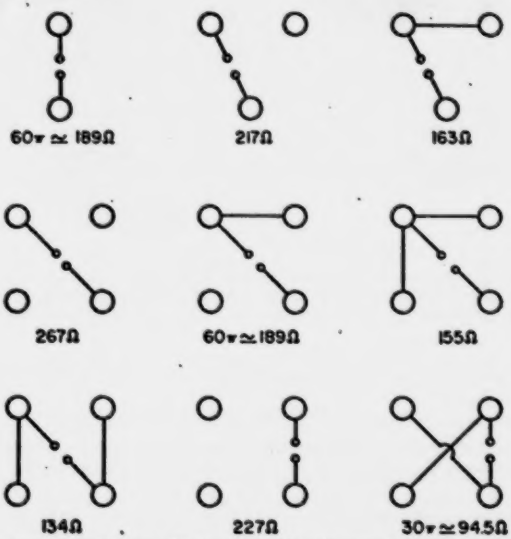



FIG. 18-13. Constant impedances obtainable with self-complementary symmetrical structures having two, three, and four terminals. The terminals of the structures are represented by the circles. After connecting them as shown in each figure, the impedance between the two dots has the value indicated under it.

Figure 18-13 gives impedances computed by this method for the symmetrical self-complementary structures with two, three, and four terminals.

**Element Characteristics.** Radiation properties of log-periodic structures may be better understood when it is realized that each of the half structures produces a unidirectional beam by itself. As mentioned earlier, the absence of end effect implies a unidirectional pattern. Although it is necessary to feed two half structures against each other or one against the ground in order to obtain wideband operation, it has been demonstrated[8] by special measurement techniques that the half structure does produce a unidirectional beam pointing in the direction of its center line. Figure 18-14 demonstrates the variation of the $E$- and $H$-plane beamwidths of a single half structure with wire trapezoidal teeth as a function of the design parameter $\alpha$. The $E$ plane is defined as the plane which includes the half structure, and the $H$ plane is the normal plane, which includes the center line of the half structure.

For a given $\alpha$ angle, there is a minimum value of the design ratio $\tau$ which can be used. For values of $\tau$ smaller than this minimum, the pattern breaks up considerably, and for larger values the beamwidths will decrease. The approximate minimum value of $\tau$ which can be used is plotted in Fig. 18-14 (solid curve) as a function of the parameter $\alpha$. The $E$- and $H$-plane beamwidths for this minimum value of $\tau$ are also shown as solid lines. The dashed curves for the $E$- and $H$-plane beamwidths correspond to the dashed curve for $\tau$, which is somewhat larger than the minimum value. It is noticed that the $E$-plane and especially the $H$-plane beamwidths decrease as $\alpha$ is decreased and

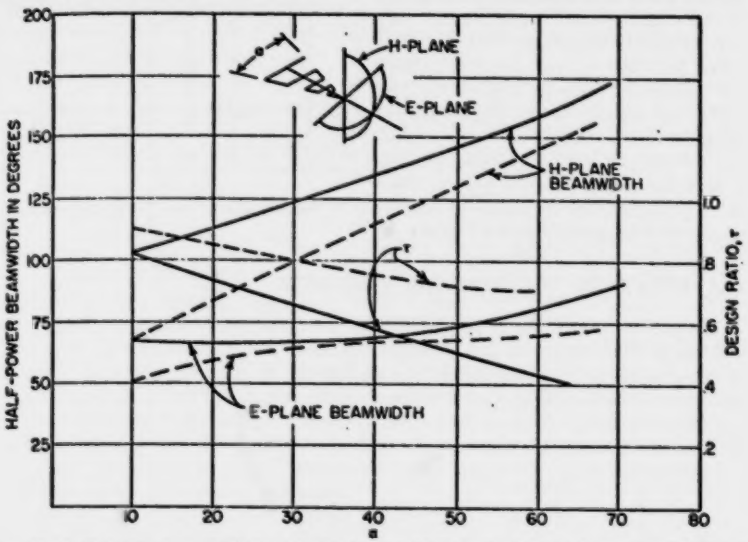



FIG. 18-14. Pattern characteristics of wire trapezoidal tooth element for: ——— Approximate minimum value of $\tau$. – – – A larger value of $\tau$.

$\tau$ is increased. For a given lower-frequency limit, which implies that the last transverse-element length remains fixed, then decreasing $\alpha$ and increasing $\tau$ means that the length of the structure and the number of transverse elements, respectively, is increased. The pattern behavior for the other types of half structures is very similar to that shown in Fig. 18-14.

An insight into the unidirectional behavior of log-periodic antennas may be gained from the dipole structure of Fig. 18-11. First, consider two parallel dipoles placed side by side with a spacing $\ell$. If the current in the dipole on the right leads the current in the dipole on the left by $\pi - \beta\ell$ (where $\beta = 2\pi/\lambda$), then the array will produce a beam to the left and a null to the right. Now, assuming for the array of Fig. 18-11 no mutual impedance between dipoles and only an incident transmission-line wave traveling to the right, it is seen that the voltage applied to a dipole leads the voltage applied to the first dipole to the left by $\pi - \beta\ell$. This suggests then that the array should produce a unidirectional pattern to the left. The same argument applies to the other types of half structures wherein the phase reversal $\pi$ is accomplished by the fact that adjacent teeth point in opposite directions from the central section which distributes current to the teeth. This phase reversal appears to be a basic requirement for frequency-independent operation of log-periodic antennas.

The pattern characteristics for the dipole structure of Fig. 18-11 with design parameters $\alpha_0$ and $\tau_0$ are nearly the same as those for a wire trapezoidal tooth structure (Fig. 18-14) with parameters $\alpha_0$ and $\tau_0$.[2]

The phase center of a log-periodic half structure does not lie at the vertex; rather it lies some distance $d$ behind the vertex. Figure 18-15 shows the distance of the phase center from the vertices as a function of $\alpha$ for wire trapezoidal tooth structures. For a fixed structure the distance as measured in wavelengths is essentially independent of frequency. For values of $\alpha$ less than 60° and for values of $\tau$ above the minimum value of $\tau$ given in Fig. 18-14, the position of the phase center is essentially independent of $\tau$. Measurements[11] indicate that $d$ depends upon $\tau$ in a complex manner for $\alpha$ greater than 60°. The phase center lies on the center line of the half structure at a point near where a half-wave transverse element exists.

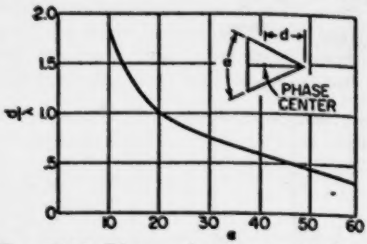



FIG. 18-15. Distance from vertex to phase center as a function of $\alpha$.

## 18.4. ARRAYS OF LOG-PERIODIC ELEMENTS

The pattern of an array of periodic elements may be considered as the simple superposition of the patterns of the individual elements if it is assumed that the presence of other elements does not affect the pattern of an element. In order to obtain frequency-independent operation with an array, it is necessary that the locations of the elements with respect to each other be defined by angles rather than distances. This implies that all the elements have their vertices or feed points at a common point.

Log-periodic arrays are unique in two respects. First, although the element patterns are identical in shape (assuming design parameters are identical), they point in different directions. Second, since the radiation from an element may be considered to emanate from the phase center, the array sources lie on the surface of a sphere for a two-dimensional array and on a circle for a one-dimensional array. Thus the array theory is more complex and much less amenable to synthesis procedures than that for linear arrays of isotropic elements.

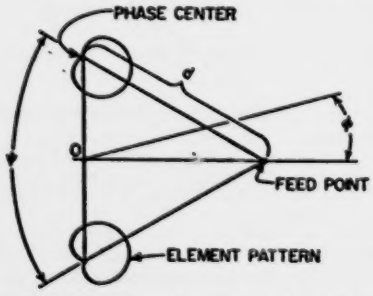



FIG. 18-16. Schematic representation of two-element array.

**Two-element-array Pattern Characteristics.** The log-periodic antennas consisting of two half structures discussed in Sec. 18.3 may be considered as an array of two elements. The pattern can easily be calculated once the element pattern and distance from the vertex to the phase center are known. A schematic representation of a two-element array is given in Fig. 18-16. The radial lines separated by the angle $\psi$ represent the two elements, and $d$ is the distance to the phase center. The direction to a distant field point is given by $\varphi$. Typical element patterns are shown in the schematic. The pattern of the array is given by

$$E = \cos^n\left(\frac{\varphi + \psi}{2}\right) \exp\left(\beta d \sin\frac{\psi}{2} \sin\varphi\right) + \cos^n\left(\frac{\varphi - \psi}{2}\right) \exp\left(-\beta d \sin\frac{\psi}{2} \sin\varphi\right) \tag{18-17}$$

where $\cos^n(\varphi/2)$ is an assumed functional form for the element pattern. Given the half-power beamwidth of an element (which may be measured or read from curves), the approximate value of the exponent $n$ may be determined from Fig. 18-17. For an $H$-plane array (like Fig. 18-10$a$) the $H$-plane beamwidth is used and for an $E$-plane array (like Fig. 18-10$b$) the $E$-plane beamwidth is used to determine $n$. The beamwidths may be obtained from Fig. 18-14. Although this procedure neglects the effect of the presence of one half structure on the pattern of the other, it will give fairly accurate results, especially for values of $\alpha$ smaller than 60°.

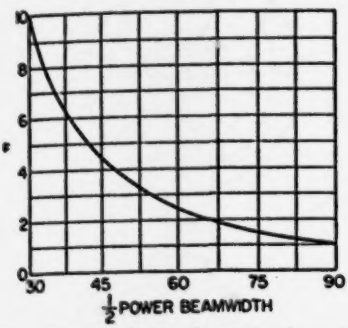



FIG. 18-17. Relation between element beamwidth and $n$.

Figure 18-18 shows the variation of the $H$-plane beamwidth, gain, and front-to-back ratio with the angle $\psi$ for a wire-trapezoidal-tooth $H$-plane array with $\alpha = 60°$ and $\tau = 0.6$. The $E$-plane beamwidth is nearly independent of the angle $\psi$, and its value is approximately 63°. Of course, for $\psi = 180°$, a bidirectional beam is produced. Notice that if both high gain and front-to-back ratio are desired, a compromise value of $\psi$ must be chosen. As to be expected, the $H$-plane beamwidth decreases rapidly with increasing $\psi$ since

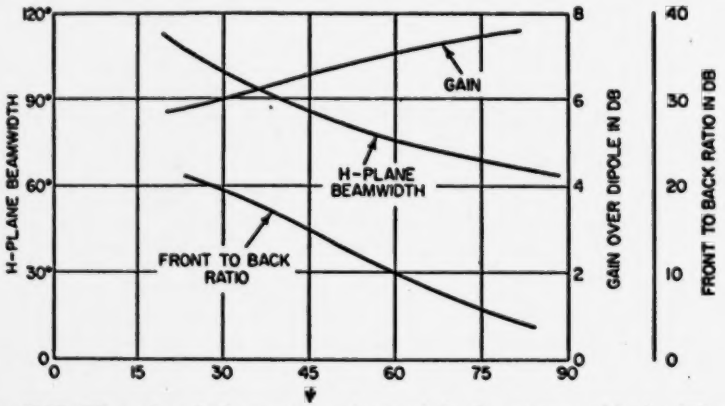



FIG. 18-18. Effect of angle $\psi$ on pattern characteristics for antenna with $\alpha = 60°$ and $\tau = 0.6$.

this effectively increases the $H$-plane aperture of the antenna. $E$-plane patterns for a structure with $\alpha = 60°$, $\tau = 0.6$, and $\psi = 35°$ are given in Fig. 18-19 over a bandwidth of 10:1. Except for $f = 60$ Mc, which is very close to the lower cutoff frequency, the beamwidth does not vary more than ±7 per cent. The $H$-plane patterns are of a similar shape but have wider beamwidths.

A split beam with a null in the direction in which the structure points can be obtained by rotating one of the half structures 180° about its center line. This effects a reversal of the phase of the half structure and may be accounted for in Eq. (18-17) by changing the sign of the second term.

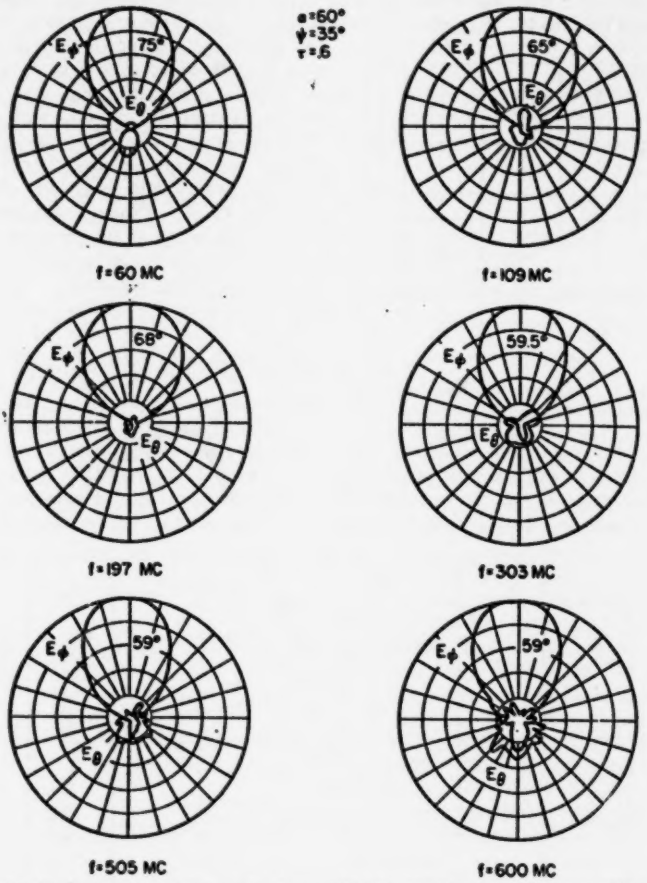



FIG. 18-19. E-plane patterns for a wire trapezoidal tooth structure with $\alpha = 60°$, $\tau = 0.6$, and $\psi = 35°$.

**Two-element-array Impedance Characteristics.** Unfortunately, insufficient information on the variation of the input impedance of log-periodic structures as a function of the defining parameters has been obtained to allow the design of antennas without resorting to considerable experimental investigation. Figure 18-20 gives some information on the variation of the characteristic impedance versus $\psi$ for various types of *H*-plane arrays. It will be noticed that in all cases the characteristic impedance decreases as the angle $\psi$ is decreased. Also, it is apparent that the characteristic impedance decreases as the angle $\alpha$ is increased. It appears, in general, that a wire

structure has a characteristic impedance somewhat higher than that for a sheet structure, with the same values of $\alpha$ and $\tau$. There does not appear to be a definite trend in variation of impedance with the $\tau$ ratio. For example, increasing $\tau$ for the wire structure increases the characteristic impedance, whereas it decreases the characteristic impedance for the circular tooth sheet structure.

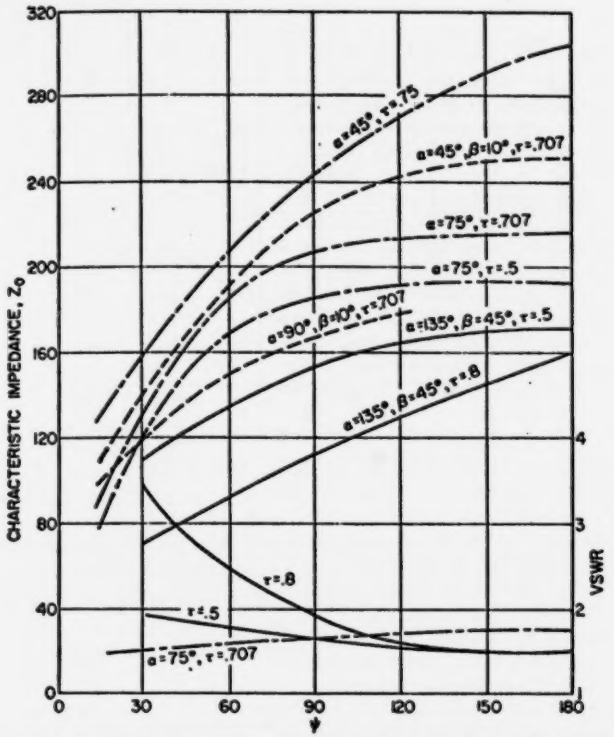



FIG. 18-20. Variation of $Z_0$ and VSWR with $\psi$ for sheet structures with: Circular teeth (— — —) Trapezoidal teeth (– – – –). Wire structure with trapezoidal teeth (— – —).

A few curves of the VSWR referred to the characteristic impedance are also given on the plot. It will be noticed that the VSWR increases, especially for the circular tooth sheet structure, with $\tau = 0.8$, as $\psi$ is decreased. For all the other structures, the VSWR remains less than 2:1 over the range of $\psi$ values considered. In some, but not all, cases it has been found that the VSWR rises rapidly as $\psi$ approaches zero for the wire structures.

The impedance variation for *E*-plane arrays is similar to that for *H*-plane arrays except that the angular spacing must be greater than $\frac{3}{2}\alpha$ in order to avoid excessive VSWR's.

For the $\psi$ values of most interest, that is, from 15 to about 90°, it is noticed that the characteristic impedance ranges from approximately 70 to 240 ohms. Thus it is necessary to use a wideband technique to match this impedance to a coaxial or a

balanced line. The tapered-line transformers described in Refs. 13 and 14 are ideally suited for matching this impedance over theoretically unlimited bandwidths. These transformers usually require a length on the order of 0.4 to 0.5 wavelength at their lowest frequency of operation.

The impedance behavior of the dipole structure of Fig. 18-11 is illustrated in Fig. 18-21. These results were obtained with a balanced-line characteristic impedance of 105 ohms.

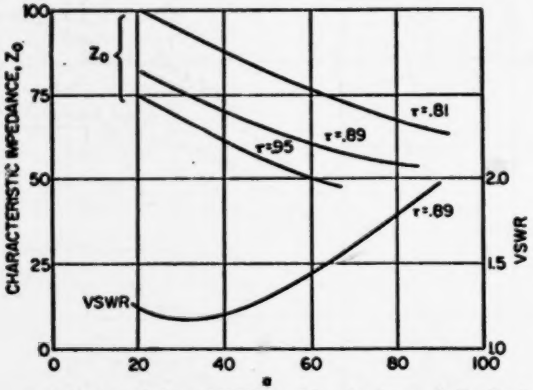



FIG. 18-21. Variation of $Z_0$ and VSWR with $\alpha$ for log-periodic dipole array.

In designing log-periodic antennas for bandwidths of 10:1 or greater, it is usually found that the characteristic impedance decreases gradually as the frequency is increased over this range. This variation is due to improper construction of the antenna; that is, it is usually not practical to taper the diameter of wires or thickness of the sheets according to theory because of mechanical limitations. However, this variation is not serious since many types of log-periodic antennas have been built with a tapered-line input transformer such that the complete system covers a 10:1 frequency range with a VSWR less than 2:1.

Several wire-trapezoidal-tooth unidirectional structures were built with $\alpha = 67\frac{1}{2}°$, $\tau = 0.6$, and $\psi = 37°$, but with the wire sizes varying over a 10:1 range. It was found that the wire size had a negligible effect on the patterns but that the characteristic impedance decreased about 30 per cent as the wire sizes increased by a factor of 10:1.

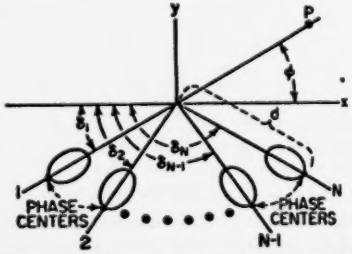



FIG. 18-22. Geometry for array of end-fire elements.

**Multielement Arrays.** A schematic representation of an array of $N$ elements as viewed from the top is illustrated in Fig. 18-22. The radial lines defined by $\delta_n$ represent the elements of the array. The $\alpha$ and $\tau$ parameters for the $N$ elements are made identical so as to assure identical element patterns. The $xy$-plane radiation pattern of the array is given by

$$E(\phi) = \sum_{n=1}^{N} A_n f(\phi - \delta_n) e^{-j[\beta d \cos(\phi - \delta_n) - \gamma_n]} \qquad (18\text{-}18)$$

where $f(\phi)$ is the element pattern and $\beta d \cos(\phi - \delta_n)$ represents the phase advance of the phase center relative to the origin. The function $f$ may take the same form as that used previously, that is, $f(\phi) = \cos^n(\phi/2)$. The value of the feed-point current for the $n$th element is given by $A_n$. In nearly all practical cases, $A_n = 1$ for all $n$. This is accomplished in practice by connecting half of the elements together and feeding them against the other half. The parameter $\gamma_n$ is the relative phase of the field radiated from the $n$th element. It may be controlled by expanding or contracting the element according to the phase-rotation principle to be described later.

The assumptions made in Eq. (18-18) are that the element patterns and input impedances are identical. Although mutual effects can make these assumptions invalid, good correlation between theory and experiment has been obtained. Cut-and-try synthesis procedures may be used with Eq. (18-18).

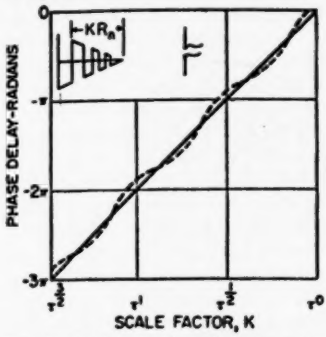



FIG. 18-23. Illustration of phase-rotation phenomena for log-periodic antennas.

A basic characteristic of logarithmically periodic antennas is the phase-rotation phenomenon. It has been verified experimentally that if the phase of the electric field received at a distant dipole (Fig. 18-23) is measured relative to the phase of the current at the feed point of the structure, the phase of the received signal will be delayed 360° as the structure is expanded through a period. In Fig. 18-23 the distance to an arbitrary transverse element is given by $KR_n$. The expansion of the structure through a period is accomplished by letting $K$ increase from 1 to $1/\tau$. During this expansion all lengths involved in the structure are multiplied by $K$. In Fig. 18-23 the phase delay in radians is plotted vs. the logarithm of $K$. The ideal phase variation is given by the solid straight line. Measurements have indicated that the actual phase variation is somewhat like the dashed line. The approximate measurements made to date indicate that the deviation of the dashed line from the straight line is not more than 15°. The relation between $\gamma_n$ and $K_n$ is given by

$$K_n = \exp\left[\frac{\gamma_n}{2\pi} \ln \tau\right] \quad , \quad (18\text{-}19)$$

Fortunately, the phase center and the element patterns are independent of the expansion or contraction of a logarithmically periodic element.

The information given above in Figs. 18-14, 18-15, and 18-23 is sufficient for predicting the pattern of an array of similar end-fire elements. The method can be extended to cover a combination of $E$- and $H$-plane arrays. The phase-rotation phenomenon is extremely important since it allows a frequency-independent method of phasing the elements of the array.

Experimental and theoretical patterns for a six-element phased-$H$-plane array of wire trapezoidal tooth elements are given in Fig. 18-24. The values of the design parameters for this array were $\alpha = 9.5°$, $\tau = 0.88$, $N = 6$, $\delta_n - \delta_{n-1} \approx 17°$ for all $n$, and $d/\lambda = 1.95$. The elements were phased to produce a beam-cophasal condition. The gain of the array was 14 db over a dipole.

Although gains up to 18 db are feasible by using a combined $E$- and $H$-plane array, the size and complexity of the antenna become great since it is necessary to use very small $\alpha$ angles and $\tau$ values near unity.

**Design Procedure.** In designing an array, a judicious choice of the parameters $N$, $\alpha$, $\tau$, and $\delta_n$ should be made so as to achieve a minimum amount of space and material and number of elements. Although the design method is cut and try, a rough approximation to an optimum design may be obtained by the following procedure. The procedure is the same for arrays in the $E$ plane and $H$ plane. Given a desired beamwidth, the equivalent broadside aperture $D$ may be calculated from

$$\frac{D}{\lambda} = \frac{40}{\phi} \tag{18-20}$$

where $\phi$ is the half-power beamwidth in degrees. The number 40 instead of 50 (which

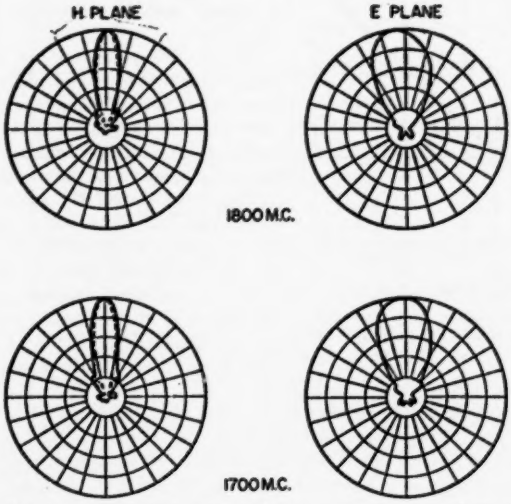



FIG. 18-24. Predicted (- - - -) and measured (———) patterns of six-element phased array.

is for a uniform aperture) is used because the end-fire directivity of the elements tends to enhance the effective aperture. The distance between the phase centers of the two outer elements must be approximately $D$. Results indicate that a reasonable maximum spacing between the phase centers of adjacent elements is 0.7 wavelength. Thus the number of elements may be determined approximately from

$$N - 1 \approx \frac{D}{0.7\lambda} = \frac{57.1}{\phi} \tag{18-21}$$

For a one-dimensional array $N$ must be even in order to present a balanced load to the feed line. The maximum value of the angle $\delta_N - \delta_1$, which defines the sector occupied by the array, depends on the beamwidth of the element pattern. If $\delta_N - \delta_1$ is greater than the element beamwidth, then elements 1 and $N$ will contribute little to the formation of the main beam. An examination of Fig. 18-14 indicates that reasonable maximum values of $\delta_N - \delta_1$ are 60° for an $E$-plane array and 70 to 130° for an $H$-plane array. If low first side lobes are desired, values somewhat smaller than the maximum should be chosen.

The distance $d$ to the phase center is equal to

$$\frac{d}{\lambda} = \frac{D}{2\lambda \sin\left(\frac{\delta_N - \delta_1}{2}\right)} = \frac{20}{\sin\left(\frac{\delta_N - \delta_1}{2}\right)} \tag{18-22}$$

The angle $\alpha$ is then determined from Fig. 18-15 since $d/\lambda$ is known. The minimum value of $\tau$ is then determined from Fig. 18-14. It is usually desirable to use the minimum value of $\tau$ since the element beamwidth has little influence on the array pattern for $N \geq 4$.

Since $A_n$ and $(\delta_n - \delta_{n-1})$ are usually made independent of $n$, the remaining parameter to determine is $K_n$. If high gain and a beam direction of $\phi_0$ are desired, then $K_n$ is chosen so that $[\beta d \cos(\phi_0 - \delta_n) - \gamma_n]$ has the same value for all $n$. Equation (18-19) gives the relation between $K_n$ and $\gamma_n$.

For shaped beams $\gamma_n$, and hence $K_n$, would be determined on a cut-and-try basis.

After the approximate synthesis given above, the array pattern may be calculated by the method of the preceding section.

The above procedure determines the parameters $\alpha$, $\tau$, $\delta_n$, $K_n$, and $N$. It remains to determine the type and size of the elements. For frequencies above about 500 Mc, a sheet structure should be used, and for ranges below that, wire structures should be used. If it is desired to cover a frequency range which overlaps 500 Mc, it may be necessary, because of mechanical considerations, to use wire construction for the back of the structure and a sheet or printed-circuit construction for the front of the structure. A gradual transition between the two types of structures may be made with only a small effect upon the electrical characteristics.

If minimum antenna size is important, rectangular or trapezoidal teeth should be used. If not, triangular teeth may be used or other similar versions. Curved teeth may also be used if the $\alpha$ angle is not too large.

The size of the element is determined from the lowest frequency required. Approximately, the largest tooth for a sheet structure should be about a quarter wavelength long at the lowest frequency and the longest transverse wire for the wire structure should be approximately a half wavelength long. The highest frequency determines the length of the shortest teeth and wires in a similar manner. For high-power or microwave applications, the size of the input cable or transmission line may limit the upper frequency.

The preceding theory and curves may be used to predict the performance of the initial design. If it is close, then the antenna model should be constructed and a pattern and impedance investigation should be performed over a period so as to determine the exact parameters. Once this is done, then the antenna should be checked over the complete frequency range, including measurement of the input impedance. It is then possible to design the tapered-line transformer for feeding the antenna.

For applications which demand minimum antenna size, it is possible to use end loading on the tips of a few of the largest teeth. The lower-frequency cutoff may be lowered 15 or 20 per cent by this means.

## 18.6. SPECIAL APPLICATIONS

**Arrays over Ground.** Although the above antennas have radiation patterns which are essentially independent of frequency, many applications demand that the antenna be placed near ground. If one of these antennas is placed with its feed point above ground, then it is apparent that the resultant pattern will be frequency-dependent since its electrical height above ground changes with frequency. However, the above array theory suggests that if log-periodic elements are inclined with respect to ground and

with their feed points at ground level, then the resultant radiation pattern will be frequency-independent. The elements can be placed so that with their images they form either *H*-plane or *E*-plane arrays or a combined *E*- and *H*-plane array. For an equivalent *H*-plane array there will, of course, be a null in the resultant pattern on the horizon. The array theory above may be used to calculate the resultant pattern by adjusting the phase of the image elements. For an *H*-plane array, the phase of the image element will be 180° different from that of the element above ground, whereas for an *E*-plane array, the phase of the image element would be the same as that of the element.

A very important application for this type of an antenna is for point-to-point communication circuits.[15] Figure 18-25 shows a two-element array above ground

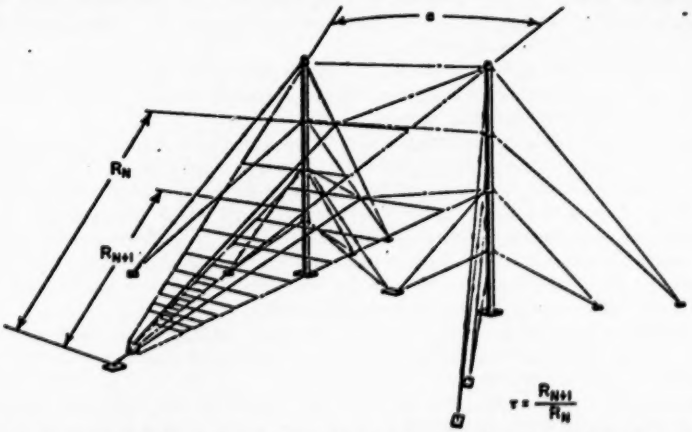



FIG. 18-25. Log-periodic H-F antenna with frequency-independent elevation pattern.

oriented so that they and their image elements form an *H*-plane array. Theoretically, the feed point of the antenna should be at ground level, but in practice the feed point is placed a small height above ground to protect personnel from high r-f voltages. Except for very short distances, high-frequency point-to-point communication is accomplished by reflection of the radio waves from the ionosphere. The vertical angle of arrival or departure (from the ground) depends upon the distance between the points and the height of the reflecting layer. Although its value ranges from 70° down to a few degrees for various circuits, its value for a particular circuit is relatively constant since the height of the reflecting layer does not change by a great amount. However, because of changing ionospheric conditions during the sunspot cycle and from night to day, it is necessary to change the operating frequency over bandwidths of 4 or 6:1. Thus it is most desirable to have an antenna for which the vertical angle of the main lobe is independent of frequency. Present-day antennas, such as the dipole, rhombic, billboard, discone, etc., do not satisfy this requirement.

The direction of the main lobe for the structure of Fig. 18-25 may be controlled by the $\alpha$ angle of the individual element and the angles of the elements with respect to ground. The size of the structure is determined by the lower-frequency limit. Figure 18-26 shows the vertical-plane pattern for a structure with $\alpha = 14°$ and $\tau = 0.75$. The two half structures are oriented at angles of 32 and 48° with respect to ground. The dimensions of the antenna at the lowest frequency are given in wavelengths in the figure. The lower half structure is scaled so that its radiation leads that of the upper

by 130°. This particular phasing increases the gain 5 db over that obtained with no difference in phasing. Although the gain for this type of antenna is only moderate (13.4 db over a dipole), maximum use of this gain is made over the complete frequency range. The gain for this structure can be increased 3 db by adding two additional elements to the side to form a combined *E*- and *H*-plane array.

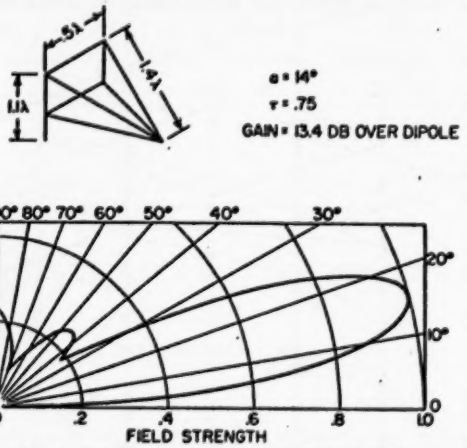



FIG. 18-26. Elevation pattern and design parameters for typical antenna of Fig. 18-25.

If vertical polarization is required rather than horizontal polarization (which is obtained for the structure above), then the two-element array can be rotated 90° about its center line so that the plane of each of the half structures would be normal to the ground plane.

**Feeds for Reflectors and Lens.** Many applications call for the use of high-gain antennas which will work over extremely wide frequency ranges. Although lens- or reflector-type antennas are ideally suited, their bandwidths have been limited in the past by that of the primary feed. Ideally, the radiation pattern and input impedance of the primary radiator should be independent of frequency; thus unidirectional log-periodic or equiangular antennas are well suited for this application. The required design information for log-periodic feeds is the primary pattern, phase-center and input-impedance.

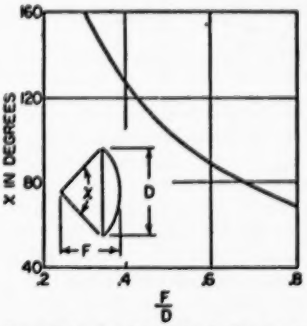



FIG. 18-27. Angle subtended by parabolic reflector as a function of $F/D$.

Figure 18-27 shows the angle subtended by a circular-parabolic reflector as observed from the focal point as a function of the $f/d$ ratio. Figure 18-28 shows the variation of the *E*-plane and *H*-plane 10-db beamwidths and the side-lobe level as a function of $\psi$ for several different values of $\alpha$ for two-element sheet trapezoidal tooth structures. The largest side lobe nearly always occurs in the opposite direction of the beam. If a 10-db taper is desired, it is seen that a two-element structure can be designed so as to give fairly good illumination tapers for $f/d$ ratios from about 0.35 to 0.6.

Another type of structure which is well suited for feeds is the triangular tooth sheet structure[14] illustrated in Fig. 18-10. Figure 18-29 shows the variation of the 10-db beamwidths for a two-element *H*-plane array of triangular tooth sheet structures as a

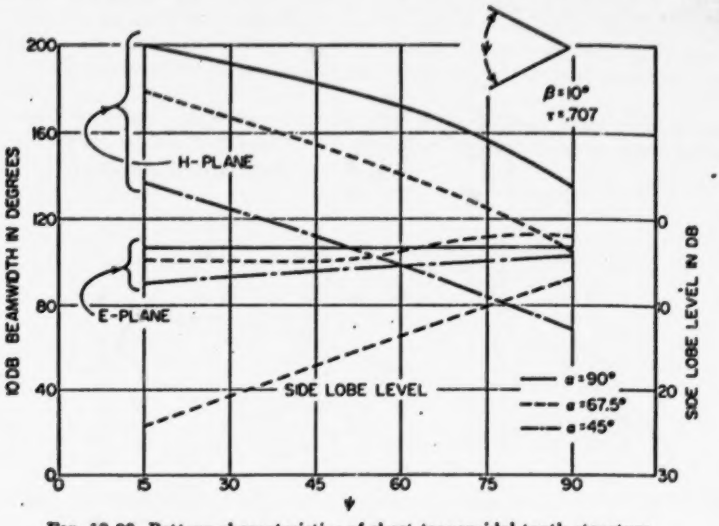



FIG. 18-28. Pattern characteristics of sheet trapezoidal tooth structure.

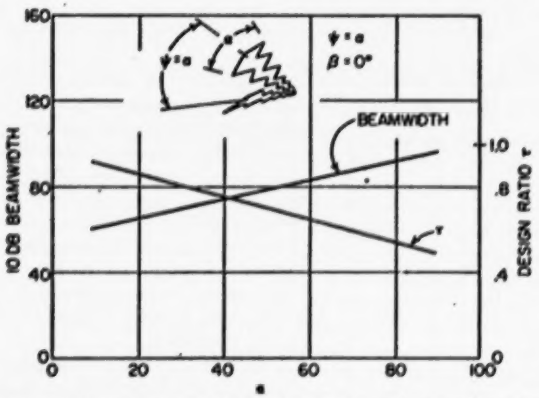



FIG. 18-29. Pattern characteristics of sheet triangular tooth structure.

function of $\alpha$ and with $\psi = \alpha$. The *E*-plane and *H*-plane beamwidths are approximately equal, so that one curve applies to both. Assuming a 10-db taper, this type of feed would be suitable for $f/d$ ratios ranging from 0.55 to 0.9.

In general, and especially for $\alpha$ angles greater than 45°, the *E*- and *H*-plane phase centers of a single element do not coincide. Except for the special case of $\psi = 0$, the *E*- and *H*-plane phase centers for a two-element *H*-plane array will not coincide even if the element phase centers do. The array phase centers will lie on a line bisecting the

center lines of the two half structures. Letting $d$ and $\ell$ represent the distances from the vertex to the element and array phase centers, respectively, it is easy to show that $\ell/\lambda$ equals $d/\lambda \cos \psi/2$ for the $E$-plane phase center provided that the element phase centers coincide and that the mutual effects between the two half structures are negligible. The positive direction of $\ell$ is toward the back end of the array. If these assumptions are not valid, then the variation of the $E$-plane phase center with $\psi$ is more complex.

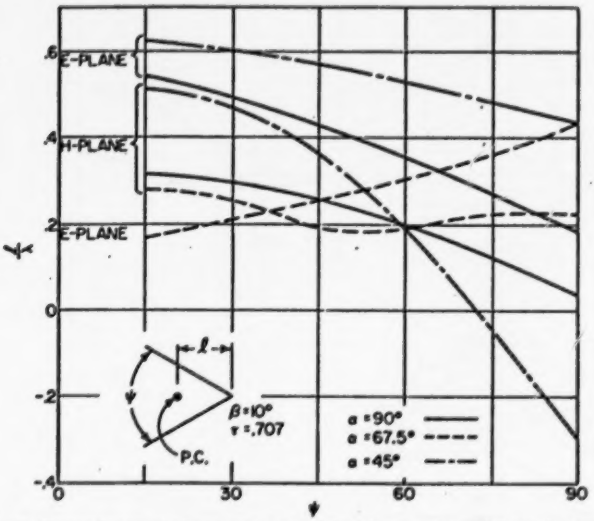



FIG. 18-30. Dependence of phase center on $\psi$ for sheet trapezoidal tooth structure.

Assuming negligible mutual effects, a simple calculation[12] leads to the following formula for the array $H$-plane phase center:

$$\frac{\ell}{\lambda} = \frac{d}{\lambda}\left(\cos\frac{\psi}{2} - \frac{\pi}{\bar{\phi}}\sin\frac{\psi}{2}\tan\frac{\psi\pi}{4\bar{\phi}}\right) \tag{18-23}$$

where $\bar{\phi}$ is the element $H$-plane half-power beamwidth. The reason for the movement of the phase center toward the vertex is that the two $H$-plane element patterns point in different directions.

Figure 18-30 shows the measured variation of $E$- and $H$-plane phase centers with $\psi$ for three values of $\alpha$ for a two-element $H$-plane array with sheet trapezoidal tooth elements. The results for $\alpha = 45°$ and 90° follow the theory fairly close, but the behavior for $\alpha = 67.5°$ is peculiar.

The variation of the phase centers with $\alpha$ for a sheet trapezoidal tooth structure with $\psi = 45°$ is illustrated in Fig. 18-31. Again peculiar results are obtained, since it would be expected that the phase center would monotonically approach the vertex as $\alpha$ is increased.

Since the phase centers will move toward the vertex as the frequency is increased ($\ell/\lambda$ is independent of frequency), it is apparent that $\ell/\lambda$ should be as small as possible. From Eq. (18-7) it is seen that the $H$-plane phase center may be made arbitrarily close to the vertex by the proper choice of $\bar{\phi}$ and $\psi$. However, a 180°$\psi$ angle is required to make the $E$-plane phase center lie at the vertex. This is undesirable because the feed

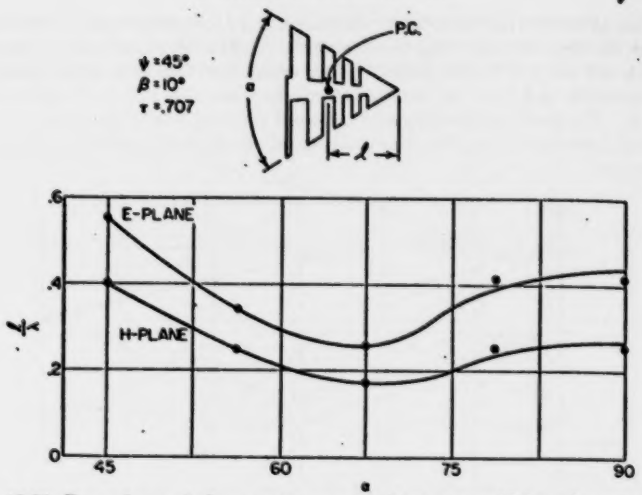



FIG. 18-31. Dependence of phase center on $\alpha$ for sheet trapezoidal tooth structure.

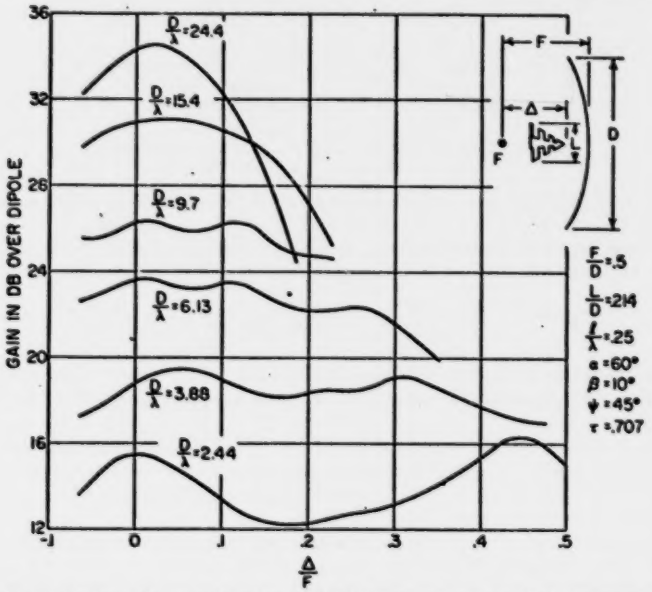



FIG. 18-33. Reflector gain as a function of feed placement over a 10:1 frequency range.

is then bidirectional and the *H*-plane phase center will lie in front of the feed. Thus it is necessary to choose a compromise value of the design parameters and allow the phase center to move with frequency.

The movement of the phase center with frequency makes it necessary to determine an optimum location of the feed for a given frequency range. This may be done by

performing the gain measurements reported in Fig. 18-32. It shows the variation of gain of a 4-ft dish at six frequencies over the frequency range of 600 to 6,000 Mc as a function of the displacement of the feed vertex from the focal point. It will be noticed that a relative displacement of 0.025 results in a maximum loss in gain less than ½ db due to movement of the phase center with frequency. In general, the feed should be located so that the phase center of the feed at the highest frequency is slightly on the dish side of the focal point. For dishes considerably larger than 4 ft over the same frequency range, the loss in gain over the band would be somewhat greater. It is possible to design a feed for use with a dish with a VSWR less than 3 and, with extreme care, less than 2 over at least a 10:1 frequency range.[12]

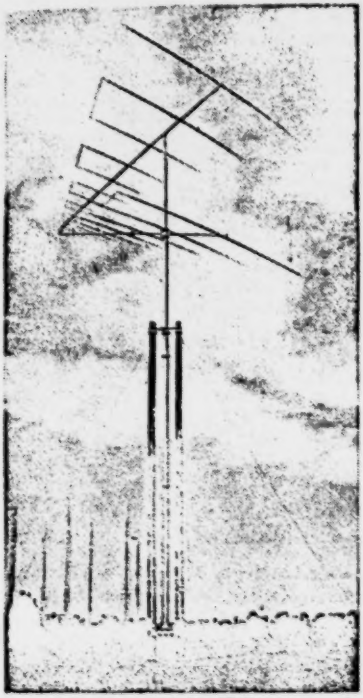


FIG. 18-33. Log-periodic H-F antenna for 11.1- to 60-Mc range (Collins Radio Co. Type 237A-2).

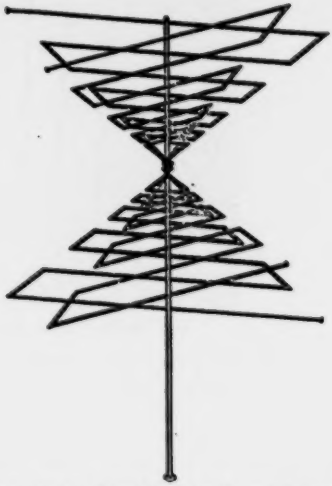


FIG. 18-34. Omnidirectional antenna with horizontal polarization.

**H-F Communications Antenna.** Figure 18-33 is a picture of a wire trapezoidal tooth structure with self-supporting elements for the frequency range of 11 to 60 Mc. The azimuthal beamwidth is about 60°, and the free-space vertical beamwidth is about 90°. The free-space gain is 8 db over an isotropic antenna, and the side lobes are more than 16 db down. The VSWR is less than 2:1. The power-handling capacity is 50 kw. The values of the design parameters for the structure are $\alpha = 60$, $\psi = 37$, and $\tau = 0.6$.

**Omnidirectional Antenna.** An omnidirectional horizontally polarized antenna is illustrated in Fig. 18-34. This consists of two planar log-periodic structures placed at right angles to each other, with one structure scaled by the factor $\tau^{1/4}$ so as to give an omnidirectional radiation pattern in the plane transverse to the axis of the antenna. This is accomplished since each planar structure produces approximately a figure-of-eight pattern and the scaling of one structure provides the 90° phase shift to give an

omnidirectional pattern similar to that obtained with a turnstile antenna. Experiments show that omnidirectional patterns within ±2 db are easily achieved over extreme bandwidths and that *H*-plane beamwidths of about 60° are easily obtained. Typical design parameters are $\alpha = 90°$ and $\tau = 0.707$ for a wire trapezoidal tooth structure.

**Circularly Polarized Antenna.** Figure 18-35 is a picture of a circularly polarized unidirectional log-periodic antenna. Two opposite half structures are fed against each

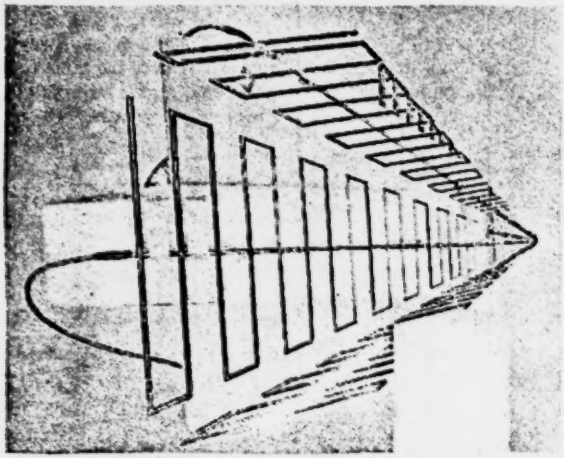


FIG. 18-35. Circularly polarized log-periodic antenna.

other to provide a linearly polarized unidirectional beam, and the other two structures are fed against each other to provide a linearly polarized unidirectional beam with orthogonal polarization. The 90° phasing between the two polarizations is obtained by scaling one pair of structures by the factor $\tau^{1/4}$. The sense of circular polarization can easily be changed by reversing the feed lines to one pair of structures. Axial ratios less than 2:1 can be obtained over extreme bandwidths, and the *E*- and *H*-plane beamwidths can be made approximately equal by proper adjustment of the design parameters $\alpha$, $\psi$, and $\tau$.

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16. D. E. Isbell: "A Log-periodic Reflector Feed," *Proc. IRE*, vol. 47, p. 1152, June, 1959.

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U.S. DEPARTMENT OF COMMERCE
PATENT OFFICE
WASHINGTON

PAPER No. 27
All communications relating to this case should identify it by number and name of parties.

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Interference No. 92,150

Isbell
vs.
Kravis et al.,

PLAINTIFF'S EXHIBIT 56

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION
56
PLAINTIFF'S EXHIBIT
DOROTHY ZEMANSKY
OFFICIAL COURT REPORTER

*find below a communication from the NER in this case.*

*Commissioner of Patents.*

## DECISION ON MOTIONS

The party Isbell moves to dissolve on the grounds that the party Kravis et al. has no right to make the count in issue.

The party Kravis et al. moves to add proposed counts 2 and 3 to the issue.

Oral hearing on both motions was held before the Primary Examiner on February 18, 1963. Mr. Samuel B. Smith appeared on behalf of the party Isbell. No appearance was made by the party Kravis et al.

## THE INTERFERING INVENTIONS

The invention at issue involves a broadband antenna of the backward wave type. It consists of a sequence of parallel dipoles whose lengths and spacings increase from the feed end. The dipoles are fed by a two wire transmission line with a line transposition between successive dipoles. The antenna exhibits a unidirectional radiation pattern off the small end with substantially constant impedance over a wide band of frequencies.

REC

RULE 5.4 CITED

Kandoian 2,129,629 Sept. 27, 1937

Channel Master Corp. "H.O." Antenna Report #4 1955; 3 pages, copy Div. 65, 313-765 TV

Logarithmically Periodic Antenna Designs by DuHamel and Ore. 1958 IRE National Convention Record, Part I, March 24-27, 1958, pages 139-151

ISBELL MOTION TO DISMISS

The party Isbell urges that Kravis et al. cannot make the count in issue since he does not teach the specific relationship between the dipole lengths and spacings as set out in the formula

$$\frac{L\,(n+1)}{Ln} = \gamma = \frac{S\,(+1)}{Sn}$$ where

L is dipole length

S is dipole spacing

n is dipole number

$\gamma$ is the scale factor

The party Isbell further contends that the broad reference to a logarithmic variation as used in Kravis et al. in no way teaches his specific relationship.

The Party Kravis et al. urge that the specific mathematical relationship in the count is implicit in all logarithmic functions. They cite authorities to show the equivalence of logarithmic and exponential functions. They show that a geometric progression is inherent in a logarithmic function. They prove that the dimensions disclosed in Isbell follow a geometric progression.

The applications have been carefully studied in

the light of the above arguments. As a result it is considered that the party Kravis et al. has not taught the specific relationship of Count 1. While it is true that the expression in question is a geometric progression and that a geometric progression is inherent in a particular logarithmic function, it is Isbell alone who teaches the specific progression in question. Stated in other words, Isbell specifically spells out his log function while Kravis et al. have not. The Isbell teaching is lead to an array bound by an isosceles triangle. No equivalent triangular structure is disclosed on the drawing of the Kravis et al. disclosure or is there any exemplary dimensions included therein from which this may be inferred. It is pointed out that many log functions may provide an array whose dipoles increase substantially logarithmically. For example, the lengths of the array could be determined by functions such as:

$$x = \log (\log y) \text{ or}$$

$$x = \log (\tan y)$$

(These two functions, used only by way of example, correspond to the log - log scale and the tangent scale of an engineer's slide rule, and the designation "logarithmetic" obviously is applicable to them). An array whose dipole lengths and spacing are determined by these functions, respectively, would be bounded by curves, and not by the straight lines taught by Isbell.

The IEEE article by Isbell mentioned in the Kravis et al. brief is consistent with the above since he uses

the phrase "logarithmically varying" to refer to specific mathematical formulas given in the article."

Isbell's motion to dissolve is granted.

THE KRAVIS ET AL. MOTION TO ADD COUNTS

The party Kravis et al. move to add proposed counts 2 and 3 to the interference. Proposed count 2 corresponds to allowed claim 1 in the Kravis et al. application and claim 10 in the Isbell application. These proposed counts are applied to the Isbell device in the Kravis et al. motion paper filed October 26, 1962.

The motion to add proposed count 2 is granted. The specific relationship disclosed in Isbell is, broadly speaking, a logarithmic function. The parallel dipoles and transposed feed line are obviously applicable to the Isbell device.

The motion to add proposed count 3 is denied since this count is considered unpatentable over the Duhamel et al. article. Fig. 2 of the article, when the angle $\psi$ is made to approach 0, shows dipoles of increasing lengths and spacings connected to a two conductor balanced feeder B. The count is also considered unpatentable over the Kandoian, Channel Master or Nathin references in view of the Duhamel et al. article. Each one of the primary references shows an array of dipoles wherein the dipole lengths and spacings are varied. Duhamel et al. teach the desirability of varying the l/λ and spacings of dipoles in increasing magnitude. As broadly as claimed, it would be obvious to so arrange the dipoles in any one of the primary references.

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SUMMARY

I The motion to dissolve as to count 1 is granted.

II The motion to add counts is granted as to proposed count 2 and denied as to proposed count 3.

III This interference will be redeclared, including the parties Isbell and Kravis et al. on the basis of count 2.

Reconsideration may be requested within the time period specified in Rule 2[illegible](c).

No appeal, Rule 2[illegible](d).

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Examiner

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[illegible]

PLAINTIFF EXHIBIT 57

Sept. 1, 1931. H. O. PETERSON 1,821,402

ANTENNA

Filed Nov. 8, 1927 2 Sheets-Sheet 1

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Fig. 1

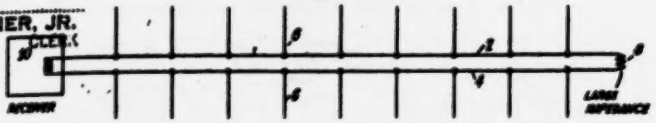


Fig. 2

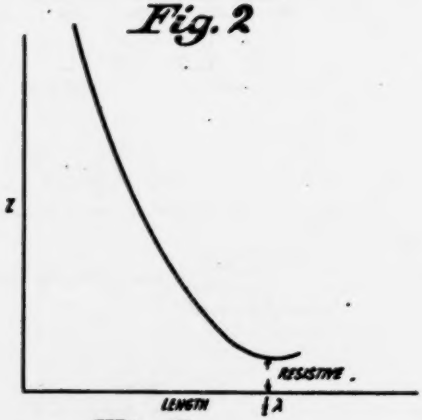


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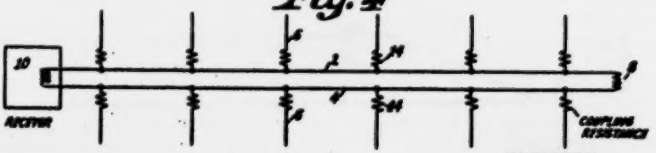
Fig. 3

Fig. 4




INVENTOR
HAROLD O. PETERSON

BY Ira J. Adams

ATTORNEY

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

Sept. 1, 1931. H. O. PETERSON 1,821,402

ANTENNA

Filed Nov. 8, 1927 2 Sheets-Sheet 2

Fig. 5

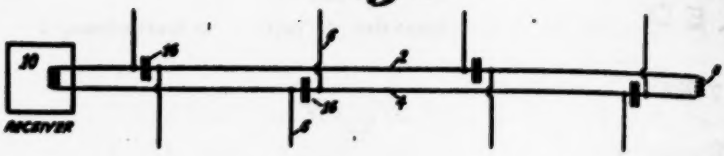



Fig. 6

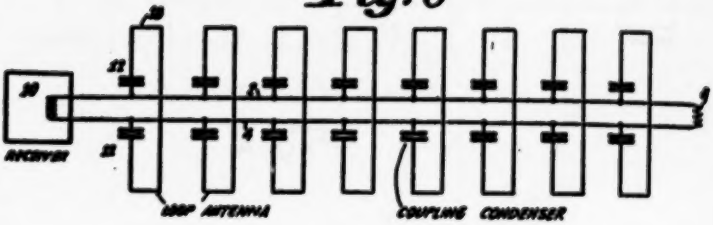



Fig. 7

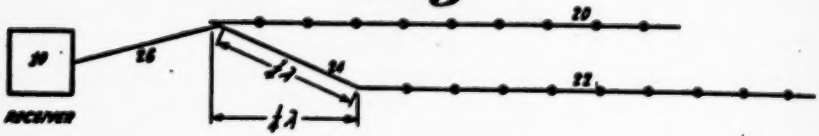
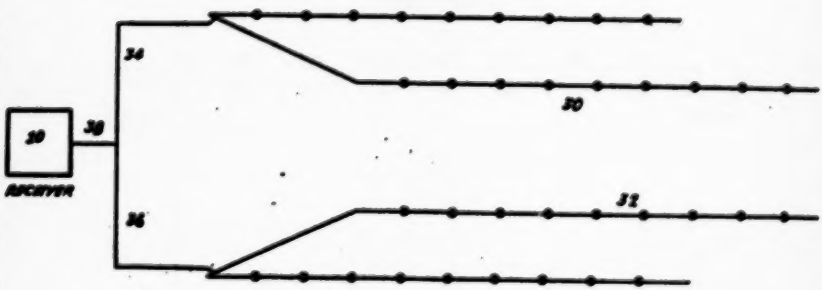



Fig. 8

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INVENTOR
HAROLD O. PETERSON
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Patented Sept. 1, 1931 1,821,402

# UNITED STATES PATENT OFFICE

HAROLD O. PETERSON, OF RIVERHEAD, NEW YORK, ASSIGNOR TO RADIO CORPORATION OF AMERICA, A CORPORATION OF DELAWARE

## ANTENNA

Application filed November 8, 1927. Serial No. 231,804.

This invention relates to antennæ for the reception of radiant energy, and more particularly to directive antennæ for the reception of signals transmitted on very short waves.

A favored type of directive receiving antenna is the wave antenna invented by H. H. Beverage, but the ordinary wave antenna is not suitable for the reception of short wave energy. The difficulty seems to be that the great reduction in the horizontal length of the antenna at short wave lengths, makes the horizontal length become comparable with the vertical height above ground, as a result of which the ordinary nondirectional antenna effect becomes comparable with the directive or cumulative antenna effect, and thereby greatly distorts the directive characteristics of the antenna.

To overcome this difficulty Clarence W. Hansell, in a copending application Serial Number 161,171, filed Jan. 18, 1927, suggested the use of a special form of wave antenna comprising two wires a plurality of waves long, spaced about a half wave apart, and extending in the direction of desired reception, with a large number of doublets or half wave antennæ coupled transversely between the longitudinal wires or feeder members. I have found that by a simple change in construction I can greatly improve the operation of such an antenna, and to so do is one object of my invention.

The energy in the transverse pickup units is applied to the feeder members at phase displacements approximating those of the wave travelling in space, and therefore in order that the energy shall add cumulatively in proper phase, it is necessary that the velocity on the feeder members be substantially equal to that of the wave in space. An ordinary transmission line will transfer energy at a velocity very closely approximating that of a wave in space, but the addition of distributed transverse impedance to such a line will cause it to have a lower velocity. The transverse pickup units, if tuned, load the line as resistances of relatively small value, and therefore greatly lower the velocity on the loaded line relative to that of light.

In the application of Clarence W. Hansell already referred to, it was suggested to overcome this difficulty by suitably tuning the line for increased velocity. I find that a much simpler way to accomplish the same result is to use pickup units of high impedance, or to loosely couple the units to the feeder members through high impedances, and to employ relatively closely spaced feeder members. The impedance of the pickup wires may be increased by making them shorter than a half wave in length, so that they are not tuned, and they are coupled externally of the feeder members, rather than between them. With this arrangement an antenna only a wave in length is markedly directive, though antennæ two or three waves in length may be used conveniently, and give even better directivity and pickup.

The facts that the feeder members, being closely spaced, do not themselves pick up received energy, that the surge impedance later referred to is in the form of an ohmic resistance, and that the transverse pickup means are untuned, being different in length from a true half wave, result in that the antenna may efficiently receive an appreciable band of frequencies, that is, the antenna is not critically tuned. This result is desirable, and to make possible the reception of an even greater band of wave lengths is another object of my invention. For this purpose I find it desirable to limit the loading which the transverse pickup means apply to the feeder members by means other than the reduction in length of the transverse doublets, for the proportional reduction in length for a given transversal varies rapidly relative to a change in wave length. I therefore couple the pickup means to the feeder members through limiting impedances, which may preferably take the form of small series condensers. By loosely coupling the pickup wires to the feeder members in this manner they have less effect upon the line velocity, and their effect remains small in spite of appreciably large variations in the length of the received wave.

It is also an object of this invention to make the antenna unilateral in directivity, which I do by closing the end of the feed line near-

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est the desired transmission station with a resistance equal to the surge impedance of the line, which absorbs energy approaching from the opposite direction, and thereby prevents its reflection back to the receiver coupled to the other end of the feed line. The damping impedance is equal to the surge impedance of the transmission line as loaded by the pickup devices.

The surge resistance at the end of the feeder members fairly effectively prevents pickup of signals coming from a direction opposite to that desired, but back end residuals will nevertheless occur, just as in the case of a long wave wave antenna. To obviate these I use a plurality of antennæ located in broadside and displaced an odd number of quarter wave lengths, relative to the wave front of the approaching wave, so that the resulting phase opposition caused by unsymmetrical coupling neutralizes the undesired signals, as will be explained in more detail later.

A still further object of my invention is to increase the sharpness of directivity of such an antenna system, which I do by employing a plurality of end-on antennæ, or of staggered pairs of antennæ, such as have already been described, positioned relatively in broadside, and coupled together by symmetrically branched transmission lines.

The invention is more completely described in the following specification, accompanied by drawings in which

Figure 1 represents an antenna embodying my invention in a simple form;

Figure 2 is a curve showing the effect of the length of a transversal on its impedance;

Figure 3 illustrates the use of coupling condensers;

Figure 4 illustrates the use of coupling resistances;

Figure 5 is a modification in which the pickup means are connected in series, rather than in parallel;

Figure 6 shows loop antennæ instead of simple transverse wires for the pickup means.

Figure 7 shows a staggered pair of antennæ; and

Figure 8 shows a broadside combination of staggered pairs of antennæ.

Referring to Figure 1 it will be seen that there is a pair of linear feeder members 2 and 4, to which there are coupled transverse pickup wires 6. The feeder members alone would transfer energy at a velocity almost equal to that of light. However, with transverse impedances connected across the line the velocity is reduced.

In Figure 2 the impedance of a transversal is shown as a function of its length. It is seen that at a half wave length the impedance is low and is resistive, the transversal being tuned. This is a condition in which the transversals most greatly reduce the desired high feed line velocity. By shortening the doublets their impedance is greatly increased, and their effect on the line velocity may be brought within allowable limits. Hence in Figure 1 the length of each transverse wire is substantially less than a half wave length.

The feeder members need be only approximately a wave in length and a good directive pattern will be obtained. But a length of two or three waves adds to the directivity and the pickup, and therefore is preferable. However, this leads to the necessity for higher line velocities, for while a velocity of about 80 percent, relative to light, is sufficient when the feeder members are only one wave long, velocities of about 90 to 95 percent are respectively needed for antennæ, three to six waves long, if the energies of the pickup wires at the remote end of the antenna are to add, rather than oppose, the line energy.

The end towards the transmitter is closed by a resistance 8, equal to the surge impedance of the feeder members, considered as a loaded transmission line, while the end remote from the transmitter is coupled to a suitable receiver 10.

In Figure 3 the arrangement is similar to that shown in Figure 1 except that the transverse pickup wires 6 have been coupled to the feeder members 2 and 4 by small series coupling condensers 12. By their use the transversals are loosely coupled to the feeder members, so that the effective loading is reduced. For this reason the transversals need not be shortened so much, or from another and more practical view point, for a given length of transversal the antenna is suitable for a greater band of applied frequencies.

Figure 4 is similar to Figure 3 except that in place of the coupling condensers 12 there have been used coupling resistances 14.

In Figure 5 I have shown a modification designed to add the potential pickup of the various transversals in series, rather than in parallel, and for this purpose the two halves of the transversal are connected on either side of a series condenser 16 to one or the other of the feeder members. By this arrangement the coupling condensers are in series with the line, and tend to increase its velocity.

So far I have assumed that the pickup means are simple transverse wires, but the same principle, namely, the limiting or reduction of the effect of the individual pickup means on the velocity characteristics of the feeder members, may equally well be applied to other types of pickup means, exemplified by the loop antennæ 18 in Figure 5. These are loosely coupled to the feeder members 2 and 4 through small coupling condensers 12.

It has already been pointed out that in spite of the surge resistance 8 some residual back end pickup may be noted at the re-

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ceiver. To completely obviate this I may resort to the arrangement shown in Figure 7 in which the pair of antennæ 20 and 22, arranged relatively in broadside but only about a tenth of a wave apart, are displaced a quarter wave length relative to the wave front of the approaching wave. The feeder members have negligible pickup, because of their close juxtaposition, and similarly the collecting transmission line 24 has negligible pickup, but there is a phase displacement in quadrature taking place across a quarter wave of its length, and therefore signals approaching from the desired direction combine in phase at the transmission line 26, for it is connected to the mid point of the remaining portion of the line 24, and the sum of the signals is applied to the receiver 10. However, energy travelling in the opposite direction reaches corresponding portions of the antennæ at a quarter wave apart in phase, and the energy from the antenna 22 experiences another quarter wave displacement in traversing the extra quarter wave length of the transmission line 24, hence the energies combine at a phase displacement of 180°, and neutralize one another. While the neutralization of residuals is perfect at only one wave length, the staggered pair of antennæ is equally good for desired signals over a full band of wave lengths, inasmuch as the signals are always combined in phase.

Figure 8 is a broadside array of staggered pairs of antennæ. The pair 30 and the pair 32 are each arranged as was the staggered pair in Figure 7, and their outputs are combined in phase by a symmetrically branched system of transmission lines comprising the lines 34, 36 and 38, the latter of which leads to a receiver 10.

I claim:

1. A directive receiving antenna for short waves comprising a pair of feeder members and a plurality of transverse pickup wires coupled to the feeder members, said pickup wires being substantially smaller than a half wave in length in order to detune them and to limit their effect on the velocity of energy transfer on the feeder members.

2. A directive receiving antenna for short waves comprising a pair of relatively closely spaced feeder members and a plurality of transverse pickup wires externally coupled to the feeder members, said pickup wires being substantially smaller than a half wave in length in order to detune them and to limit their effect on the velocity of energy transfer on the feeder members.

3. A directive receiving antenna for short waves comprising a pair of relatively closely spaced feeder members extending in the direction of desired reception and a plurality of transverse pickup wires externally coupled to the feeder members, said pickup wires being substantially smaller than a half wave in length in order to detune them and to limit their effect on the velocity of energy transfer on the feeder members.

4. A directive receiving antenna for short waves comprising a pair of relatively closely spaced feeder members extending in the direction of desired reception, a plurality of transverse pickup means arranged externally of the feeder members, and relatively high impedances loosely coupling the pickup wires to the feeder members in order to limit the effect of the impedance of the pickup means on the velocity of energy transfer on the feeder members.

5. A directive receiving antenna for short waves comprising a pair of relatively closely spaced feeder members extending in the direction of desired reception, a plurality of transverse pickup means arranged externally of the feeder members, and small condensers coupling the pickup means to the feeder members in order to limit the effect of the impedance of the pickup means on the velocity of energy transfer on the feeder members.

6. A directive receiving antenna for short waves comprising a pair of relatively closely spaced feeder members extending in the direction of desired reception, a plurality of transverse pickup means externally coupled to the feeder members, and a resistance equal to the surge impedance of the system connected across the end of the feeder members nearer the desired transmission station.

7. A directive receiving antenna for short waves comprising a pair of relatively closely spaced feeder members extending in the direction of desired reception, a plurality of pickup wires transversely and externally positioned relative to the feeder members, a plurality of impedances loosely coupling the pickup wires to the feeder members, and a resistance equal to the surge impedance of the system connected across the feeder members at the end nearer the desired transmission station.

8. A directive receiving antenna for short waves comprising a plurality of pairs of relatively closely spaced feeder members each extending in the direction of desired reception and located relatively in broadside, a plurality of transverse pickup means externally coupled to the feeder members, said pickup means being detuned to limit their effect on the velocity of energy transfer on the feeder members and a transmission line system interconnecting the feeder members in proper relation to combine their energies cophasially.

9. A unilaterally directive receiving antenna for the reception of short waves comprising a pair of relatively closely spaced feeder members each extending in the direction of desired reception and located relatively cosely in broadside but staggered an odd number of quarter wave lengths relative

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to the wave front of an approaching wave, a plurality of transverse pickup means externally coupled to the feeder members, and means for combining the energies of the feedor members cophasially with respect to energy approaching from the desired direction, whereby reflected energy pickup from energy travelling in the opposite direction is combined in phase opposition.

10. A unilaterally directive receiving antenna for the reception of short waves comprising a pair of relatively closely spaced feeder members each extending in the direction of desired reception and located relatively in broadside but staggered a quarter wave length relative to the wave front of an approaching wave, a plurality of transverse pickup means externally coupled to the feeder members, a collecting transmission line connecting the ends of the feeder members remote from the desired transmission station, a receiver, and a transmission line unsymmetrically coupling the receiver to the collecting transmission line in order to introduce a quarter wave change in phase.

11. A unilaterally directive receiving antenna for the reception of short waves comprising a plurality of staggered pairs of antennæ located in broadside, each pair of antennæ comprising a plurality of pairs of relatively closely spaced feeder members extending in the direction of desired reception, and located relatively in broadside but staggered an odd number of quarter wave lengths relative to the wave front of an approaching wave, a plurality of transverse pickup means externally coupled to the feeder members, means for combining the energies of the feeder members in each pair of antennæ cophasially with respect to energy coming from the desired direction, whereby reflected energy pickup from energy travelling in the opposite direction is neutralized, and means for combining the energies from all of the pairs of antennæ in proper phase for utilization in a receiver.

12. An extensive antenna system for receiving electromagnetic waves comprising closely spaced, substantially linear feeder members and transverse pick-up conductors symmetrically coupled thereto through series resistances.

13. An extensive antenna system for receiving electromagnetic waves comprising closely spaced, substantially linear feeder members and a plurality of pick-up conductors transversely, externally and symmetrically coupled thereto through series resistances.

14. An extensive antenna receiving system comprising feeder members and a plurality of conductive pick-up elements transversely and externally coupled thereto through series limiting impedances.

15. A directive antenna system for receiving electromagnetic waves comprising a two conductor transmission line linear throughout its length, a plurality of linear pick-up elements parallel to each other arranged in one plane, a limiting impedance for connecting each of said elements externally to one of said conductors, another plurality of pick-up elements parallel to each other and arranged in the same plane as the plane of said first mentioned plurality of elements, and, an impedance, in series with each of said elements of said second mentioned plurality for connecting each of said elements to the other conductor of said line.

16. A directive receiving antenna for short waves comprising a pair of relatively closely spaced conductors linear and continuously conductive throughout their length forming a transmission line extending in the direction of desired reception, a plurality of linear pick-up elements externally coupled to one of said conductors, all of the said pick-up elements being parallel and lying in one plane, another plurality of linear pick-up elements parallel to each other lying in the same plane as said first mentioned plurality of elements, coupled to the other conductor of said line, and, an impedance, equal to the surge impedance of the system connected across the end of the transmission line nearer the desired transmission station.

17. A receiving system as defined in claim 16 characterized by the additional feature that each of the pick-up elements is coupled to its linear conductor through a series impedance.

HAROLD O. PETERSON.

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Report No.

ANTENNA LABORATORY

Quarterly Engineering Report

# RESEARCH STUDIES ON PROBLEMS RELATED TO ECM ANTENNAS

PLAINTIFF'S EXHIBIT 70

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
PLAINTIFF'S EXHIBIT 70

This report is not to be announced or distributed automatically, in accordance with AFR 205-43A, Paragraph 6d.

Contract No. AF33(616)-6079
Project No. 9-(13-6278) Task 40572

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# RESEARCH STUDIES ON PROBLEMS RELATED TO ECM ANTENNAS

PLAINTIFF'S EXHIBIT 71

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION
PLT. 71
CLERK, U.S. DISTRICT COURT

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Contract No. AF33(616)-6079
Project No. 9-(13-6278) Task 40572

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March 5, 1940. M. KATZIN 2,192,532

DIRECTIVE ANTENNA

Filed Feb. 3, 1936

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA
DEFENDANT'S EXHIBIT NO. 3
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER.

Fig. 1

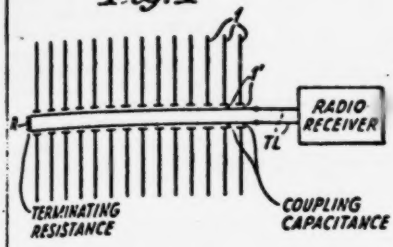



Fig. 2

Fig. 3a

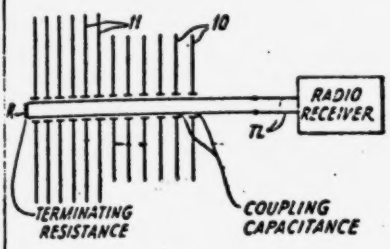



Fig. 3b

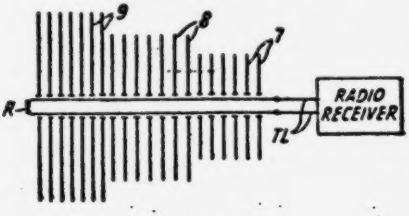



Fig. 3c

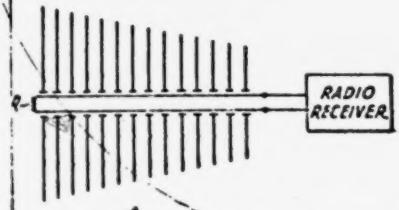



Fig. 4

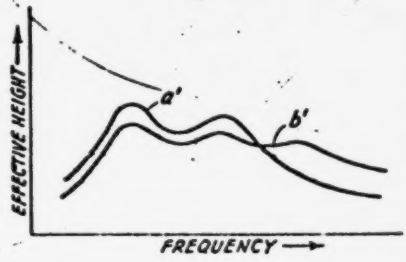
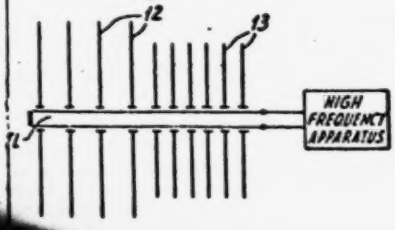



Fig. 3d

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INVENTOR
MARTIN KATZIN

BY H. B. Brower

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# UNITED STATES PATENT OFFICE

2,192,532

## DIRECTIVE ANTENNA

Martin Katzin, Riverhead, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application February 3, 1936, Serial No. 62,014

11 Claims. (Cl. 250—33)

This invention relates to directive antennas and more particularly to directive receiving antennas of the so-called "fishbone" array.

The directive "fishbone" receiving array now used in commercial radio reception consists of a number of parallel, equally spaced, similar size collector wires or doublets connected through small coupling capacitors to a common transmission line which conducts the signal to the radio receiver. The length of the collector wires and the size of the coupling condensers are chosen to give maximum received signal for a desired band of frequencies. Such an arrangement is described in U. S. Patent No. 1,821,402, granted September 1, 1931, to Harold O. Peterson. It has been found, however, that this antenna array responds rather markedly to only a relatively small frequency band, so that it is necessary to use several arrays to effectively cover the commercial frequency spectrum.

The present invention provides an improved directive antenna in the form of a "fishbone" array which gives more uniform response over a wide frequency band and thus makes it possible to efficiently receive over a much wider frequency spectrum, so that for a given frequency range to be covered, a smaller number of antenna arrays will be required.

A better understanding of the present invention may be had by referring to the following detailed description which is accompanied by drawing wherein:

Fig. 1 illustrates a known type of antenna in the form of a so-called "fishbone" array;

Fig. 2 is a graph showing curves explanatory of the operation of Fig. 1;

Figs. 3a, 3b, 3c and 3d illustrate four different embodiments of the present invention; and

Fig. 4 is a graph showing curves explanatory of the operation of the antennas of the invention.

Referring to Fig. 1, there is shown a directive antenna of known type comprising a two wire transmission line TL to which are coupled transverse doublets 1. The wires of transmission line TL are closely spaced in order to avoid their picking up received energy. One terminal of the transmission line is connected to suitable high frequency apparatus, herein indicated conventionally in box form by the designation "radio receiver." To make the antenna unilateral in directivity, the end of the line TL nearest the desired transmitting station and farthest removed from the radio receiver is closed by a suitable terminating resistance R whose impedance is equal to the surge impedance of the line as loaded by energy collecting doublets 1. Resistance R absorbs energy approaching from the direction of the radio receiver and thereby prevents its reflection back to the receiver.

The energy collecting doublets 1 are preferably untuned and coupled externally to the feeder members through limiting impedances, herein shown preferably in the form of small series condensers 1'. United States Patent No. 1,900,336 describes a type of coupling condenser commonly used in this type of antenna. By loosely coupling the doublets to the transmission line TL in this manner, they have less effect upon the velocity of the wave in the line, and their effect remains small in spite of appreciably large variations in the length of the received waves. Since this type of antenna is well-known in the art no further description is herein deemed necessary, except perhaps to refer to United States Patent No. 1,821,402, supra, which describes such an arrangement.

Fig. 2 shows various graphs illustrating frequency versus effective height characteristics of an antenna of the type shown in Fig. 1. Graph a is the frequency response curve for a "fishbone" antenna having one particular length of doublet wire and value of coupling condenser. Graph b shows a similar frequency response curve for a shorter length of doublet, and graph c represents a frequency response curve for a still shorter length of doublet.

Referring to Fig. 3a which illustrates one embodiment of the present invention, there are shown two sets of doublets 10 and 11 having different lengths, all capacity coupled to the line TL in the same manner as shown in Fig. 1. The doublets 10 and 11, it will be observed, are grouped together in two different lengths.

Fig. 3b shows another embodiment of the invention which is quite similar to the system of Fig. 3a except that there are here shown a "fishbone" array having groups of doublets of three different lengths, namely 7, 8 and 9. In this embodiment doublets 9 contribute the greater portion of the energy at the lower frequencies, doublets 8 at intermediate frequencies and doublets 7 at the higher frequencies. Now, at the higher frequencies where doublets 7 are contributing the greater portion of the signal energy doublets 9 may load the transmission line TL quite heavily. Therefore, it is advantageous to place these doublets ahead of doublet 7 so that the useful signal energy passing from 7 to the transmission line and thence to the receiver is not absorbed by the loading of doublets 9.

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Fig. 3c illustrates a still further embodiment of the invention wherein there is employed a tapered array comprising doublets which taper continuously in length from one end of the antenna to the other.

In Fig. 3d, which illustrates a further embodiment, the spacings between adjacent doublets along the transmission line TL are made greater for the longer doublets 12 than for the shorter ones 13. In this manner there is obtained roughly the same number of doublets per wavelength along the transmission line of the mean operating frequency for those doublets in each group.

Reverting for a moment to the graphs of Fig. 2, it will be evident that each group of collector doublets of a particular length will respond most efficiently to its corresponding band of frequencies, so that the combination of two or more of such groups, as represented by curves *a*, *b* and *c*, will give the result of high response for a wider frequency band.

Figs. 3a, 3b and 3c employ this principle and give the result of high response for a wider frequency band, as shown in the two curves *a'* and *b'* of Fig. 4, which represent respectively the arrangements of Figs. 3a and 3b. The use of a tapered array such as shown in Fig. 3c results in a more uniform response over the desired frequency spectrum.

The capacitors through which the doublets of Figs. 3a, 3b, 3c and 3d are coupled to line TL need not be all of equal capacitance but rather the capacitance should be properly proportioned for each length of doublet to give optimum transfer of voltage to the line TL without imposing adverse loading. The method of selecting the desired value of capacitance is well known in the art.

It is to be distinctly understood that the present invention is not limited to the precise arrangements shown and described since various modifications may be made without departing from the spirit and scope of the invention. It should also be understood that although the invention has been described particularly with reference to a receiving system, it is not limited thereto since the antenna may equally well be used for transmitting purposes. Although the doublets have been shown capacitively coupled to the transmission line TL, it should be understood that the "fishbone" type of array is not limited to such manner of coupling, since the doublets may, if desired, be alternatively connected either resistively or directly to the line TL in the same manner as described in United States Patent No. 1,841,402, supra, and the present invention is applicable to any of these or other types of "fishbone" antennae wherein any desired type of coupling is used between doublets and line.

What is claimed is:

1. A directive receiving antenna comprising a transmission line, high frequency apparatus coupled to said line, and a plurality of transverse relatively closely spaced aerial elements of different lengths loosely coupled to said line for enabling communication with waves over a relatively wide frequency band, said antenna being aperiodic for waves of all frequencies in said band.

2. A directive receiving antenna capable of receiving a wide band of frequencies comprising a straight two wire transmission line, a plurality of relatively closely spaced doublets of different lengths externally and loosely coupled to said line transversely, each doublet having two arms which are coupled to different wires of said line, and high frequency apparatus coupled to one end of said line, said antenna being aperiodic for waves of all frequencies in said band.

3. A directive receiving antenna capable of receiving a wide band of frequencies comprising a two wire transmission line, a plurality of doublets of different lengths externally coupled to said line transversely, each doublet having two arms which are coupled to different wires of said line, high frequency apparatus coupled to one end of said line, and a resistance substantially equal to the surge impedance of said line as loaded by said doublets coupled to the other end thereof, said doublets having lengths which decrease from the end at which said resistance is located toward said high frequency apparatus, said antenna being aperiodic for waves of all frequencies in said band.

4. A directive antenna comprising a transmission line, high frequency apparatus coupled to said line, and a plurality of transverse aerial elements of different lengths coupled to said line for enabling communication with waves over a relatively wide frequency band, each of said aerial elements comprising a pair of arms capacitively coupled externally to said line, there being a group of aerial elements for each different length, said antenna being aperiodic for waves of all frequencies in said band.

5. A directive antenna for communication over a band of frequencies comprising a transmission line, high frequency apparatus coupled to said line, and a plurality of relatively closely spaced aerial elements continuously decreasing in length toward said high frequency apparatus, said elements being loosely coupled to said line, said antenna being aperiodic for waves of all frequencies in said band.

6. A directive receiving antenna capable of receiving a wide band of frequencies comprising a relatively closely spaced straight two wire transmission line, a plurality of energy pick-up doublets coupled transversely and externally to said line, each doublet having two arms which are coupled capacitively to different wires of said line, high frequency apparatus coupled to one end of said line and a damping resistance coupled to the other end of said line, said doublets being divided into groups having different lengths of conductors, said antenna being aperiodic for waves of all frequencies in said band.

7. A directive receiving antenna comprising a transmission line, high frequency apparatus coupled to said line, and a plurality of aerial elements, all of different lengths, continuously tapering in length from one end of said antenna to the other and coupled capacitively to said line, the longest aerial element being located farthest from said high frequency apparatus, said antenna being aperiodic over a wide band of frequencies.

8. A directive antenna comprising a straight transmission line, high frequency apparatus coupled to said line, and a plurality of transverse relatively closely spaced aerial elements of different lengths loosely coupled to said line for enabling communication with waves over a relatively wide frequency band, said antenna being aperiodic for waves of all frequencies in said band.

9. A directive antenna comprising a transmission line, high frequency apparatus coupled to said line, and a plurality of relatively closely spaced aerial elements of different lengths coupled



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to said line through limiting impedances for enabling communication with waves over a relatively wide frequency band, said antenna being aperiodic for waves of all frequencies in said band.

10. A directive antenna comprising a transmission line, high frequency translating apparatus coupled to said line at one end, and three groups of transverse aerial elements of different lengths coupled to said line along the length thereof for enabling communication with waves over a relatively wide frequency band, the aerial elements in each group being of the same length, each of said aerial elements comprising a doublet having a pair of arms capacitively coupled externally to said line, said doublets increasing in size from the end of the line to which the translating apparatus is coupled, said antenna being aperiodic for waves of all frequencies in said band.

11. A directive antenna comprising a transmission line, high frequency apparatus coupled to said line, and a plurality of groups of aerial elements of different lengths coupled to said line along the length thereof, the spacings between adjacent elements for the longer elements being greater than for the shorter elements, said antenna being aperiodic over a wide band of frequencies.

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APPENDIX C

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# CHANNEL MASTER
## "K.O"-model 1023

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# CHANNEL MASTER
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NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 6
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

# LOGARITHMICALLY PERIODIC ANTENNA DESIGNS

R. H. DuHamel and F. R. Ore
Collins Radio Company
Cedar Rapids, Iowa

## Summary

Research on new types of broadband logarithmically periodic antenna structures is reported. The antennas have pattern and impedance characteristics which are essentially independent of frequency over theoretically unlimited bandwidths. Bandwidths of ten to one are readily achieved in practice. Structures are described which provide linearly polarized omnidirectional, bidirectional and unidirectional patterns as well as circularly polarized bidirectional and unidirectional patterns.

## Introduction

The subject of this paper is a class of antennas, called logarithmically periodic antenna structures, for which the pattern and impedance are essentially independent of frequency over theoretically unlimited bandwidths. Research on one particular type of these structures which provided a linearly polarized bidirectional beam was previously reported.[1] Since that time, various types of these structures have been discovered which provide linearly polarized unidirectional and omnidirectional patterns as well as circularly polarized unidirectional patterns. The proven versatility and wide bandwidth of these structures leads to the conclusion that the applications are practically unlimited. Obvious applications are to high-frequency and ECM antennas as well as to primary feeds for reflector and lens-type antennas.

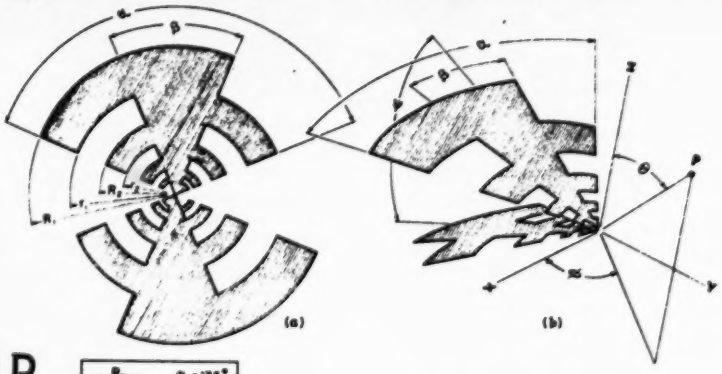
The only other known class of frequency independent antennas is the angular antenna described by V. H. Rumsey.[2] Common examples are the discone, biconical, and bow-tie antennas which have bandwidths of approximately 2 or 3 to 1 for which the pattern is essentially independent of frequency. The so-called "end effect" limits the bandwidth of these antennas. An example of a recent type of angular antenna which apparently has negligible "end effect" is the equiangular or logarithmic spiral antenna[3] which has a frequency independent bandwidth of better than 10 to 1.

Referring to figure 1, the geometry of logarithmically periodic antenna structures is defined so that the pattern and impedance repeat periodically with the logarithm of the frequency. For planar structures, this is accomplished by defining their shape such that $\theta$ equals a periodic function of $\ln r$ where $r$ and $\theta$ are the polar coordinates in the plane. Then if $\ln \tau$ is the period of $\ln r$, the operation of a structure of infinite extent would be the same for any two frequencies related by some integral power of $\tau$. For the simple structure in figure 1a:

$$\tau = \frac{R_{N+1}}{R_N}$$

If the shape of the structure and the factor $\tau$ can be made such that the variation of the pattern and impedance over one period is small, then this will hold true for all periods, the result being an extremely broadband antenna. For finite structures, it has been found that since the end effect is negligible, wide bandwidths are readily obtained.

The two halves of the antenna are fed at the vertices either with a balanced two-wire line or with a coaxial line running up one half of the structure with the outer conductor bonded to the structure. For the structure of figure 1a, it is found that the lower and higher frequency limits are obtained when the longest and shortest teeth respectively are approximately 1/4 wavelength long. By probing the structure, it is found that the currents on the structure die off quite rapidly after progressing past the region where a tooth 1/4 wavelength long is positioned. This accounts for the negligible end effect. This antenna has a horizontally polarized bidirectional pattern with approximately equal and constant principal




| | |
|---|---|
| $\tau = \frac{R_{n+1}}{R_n}$ | $\alpha = 135°$ |
| | $\beta = 45°$ |
| $\sigma = \frac{r}{R_n}$ | $\tau = .5$ |

Fig. 1 Parameters and coordinate system for circular-tooth structures.

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plane beamwidths over a frequency band of 10 to 1 or more and has a constant input impedance of approximately 170 ohms. The axes of the lobes are perpendicular to the plane of the structure. It was originally believed that it was necessary to make these structures identical to their complement in order to obtain a frequency independent input impedance. However, the results reported in this paper demonstrate that this equi-complementary condition is sufficient but not always necessary. Several frequency independent antennas will be introduced where the deviation from the equi-complementary condition is quite severe.

The fact that the electrical characteristics of logarithmically periodic structures repeat every period greatly simplifies the experimental investigation of them because it is only necessary to measure these characteristics over a half or single period in most cases. The operation over other periods may be readily predicted provided the end effect is negligible and that all dimensions are made proportional to their distance from the vertex.

As illustrated in figure 1b, D. E. Isbell[6] found that by bending the curved tooth structure about a horizontal axis, a unidirectional pattern pointing in the direction of the positive y axis could be obtained. Some control of the principal plane beamwidths and front-to-back ratio was obtained by varying the parameters $\alpha$, $\beta$, $\psi$, and $\tau$. Typical E-plane and H-plane beamwidths of 60° and 90° and a front-to-back ratio on the order of 10 to 15 db were obtained. It was found that the characteristic impedance of the structure decreased as the angle $\psi$ was decreased, but that the VSWR referred to this characteristic impedance increased rather rapidly to 3.5:1 for $\psi$ = 30°.

A great number of logarithmically periodic antenna configurations are possible. The investigation reported in this paper was conducted to study impedance, pattern and polarization characteristics of a variety of structures. Another objective of the investigation was to devise practical forms of this type of antenna. Since large circular tooth structures would be difficult to construct, the possibility of simplifying this basic structure by straightening the teeth and by making wire approximations of the teeth was investigated and is reported in the following sections.

## Trapezoidal Tooth Sheet Structures

Figure 2 shows a sketch of a general trapezoidal tooth structure and gives a definition of the coordinate system and various parameters that will be used throughout this paper to describe the various structures. Figure 3 is a photograph of a printed circuit board form of this type of structure which was used for the experimental investigation. By comparing a structure cut from sheet metal in a conventional way to an identical structure etched on teflon dielectric printed circuit

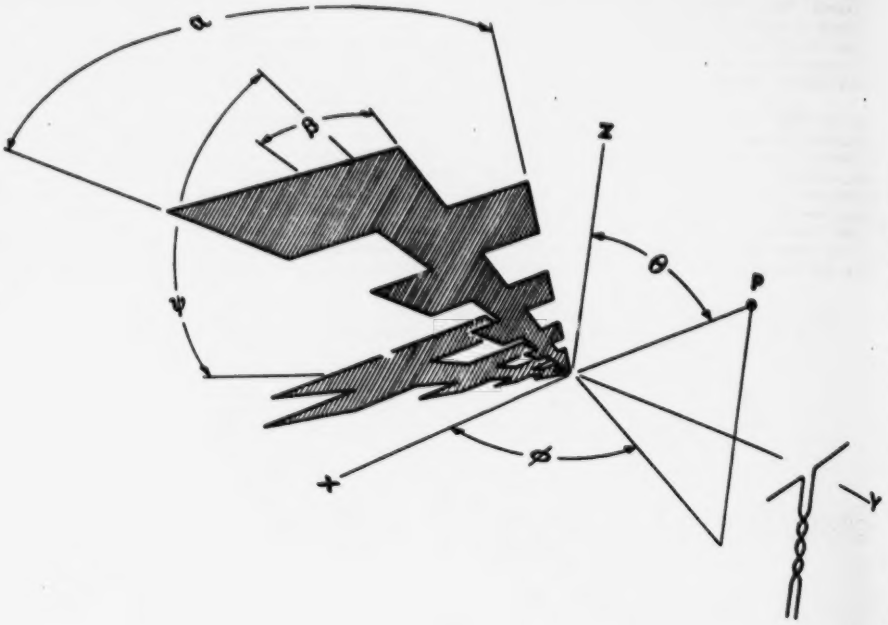


Fig. 2 Parameter and coordinate system for trapezoidal-tooth structures.

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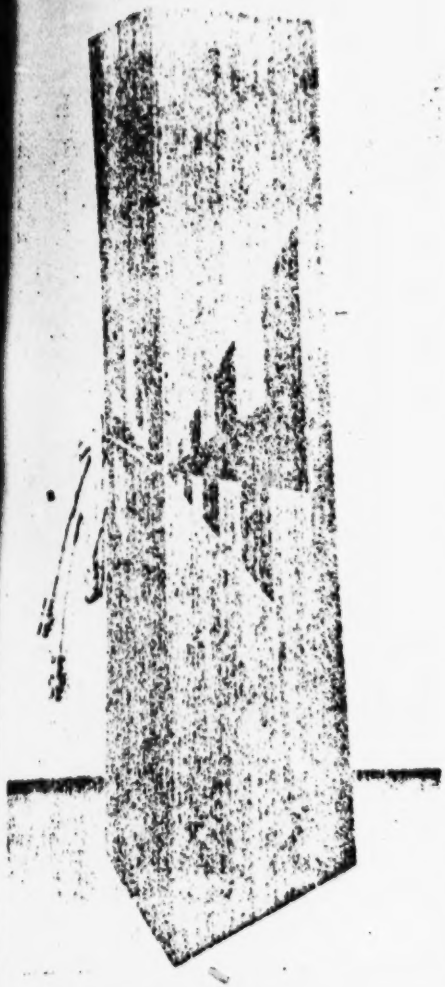

Fig. 3 A printed, nonplanar, trapezoidal-tooth structure bent about the X axis.

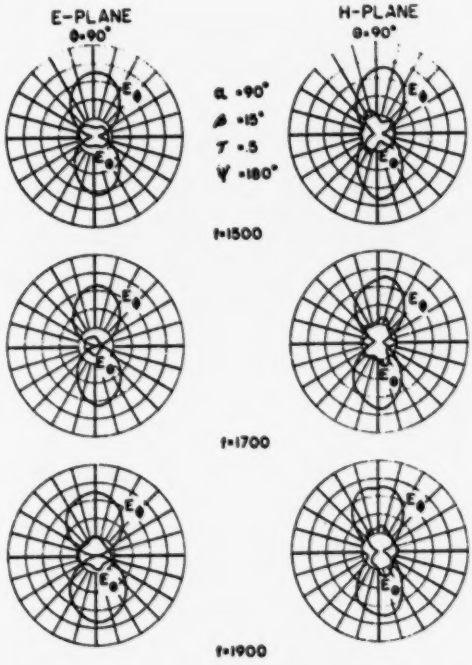


Fig. 4 Patterns for planar trapezoidal-tooth structure.

board, it was found that the printed circuit board models could be used up to about 3000 mc without the presence of the dielectric becoming too objectionable. As a point of interest, the undesired metal can be removed either by an etching process or by cutting around the outline of the structure with a sharp instrument and then peeling the metal away. Two models of planar structures (with $\psi = 180°$) were constructed with the following parameters: $\alpha = 90°$, $\beta = 30°$ for one and $\beta = 15°$ for the other, $\tau = 0.5$, and $R_1$, the perpendicular distance from the vertex of one-half the structure to the longest element, is 12.75 cm. Patterns were taken over about a two to one frequency range (900 to 2100 mc). Figure 4 shows typical patterns for this type of structure. In general, both structures gave essentially frequency independent, linearly polarized, bidirectional patterns. Over the frequency range stated above, the E-plane (pattern in the xy plane of figure 1b) half-power beamwidth varied from 65° to 80° with an average beamwidth of 71°, and the H-plane (pattern in the yz plane of figure 1b) half-power beamwidth varied from 60° to 69° with an average beamwidth of 62°. Of the two antennas tested, the one having the narrower center section ($\beta = 15°$) demonstrated slightly less variation of beamwidth with frequency.

Patterns were taken for a nonplanar structure with $\psi = 60°$ over a 5:1 frequency range. Typical patterns are shown in figure 5. The E-plane patterns were unidirectional with beamwidths that varied from 60° to 75° with an average beamwidth of 65° and the H-plane patterns had beamwidths that varied from 80° to 110° with an average beamwidth of 85°. The front-to-back ratio, due to the cross polarization $E_\theta$, had an average value of about 9 db; the front-to-back ratio, due to the major polarization $E_\phi$, had an average value of about 13 db.

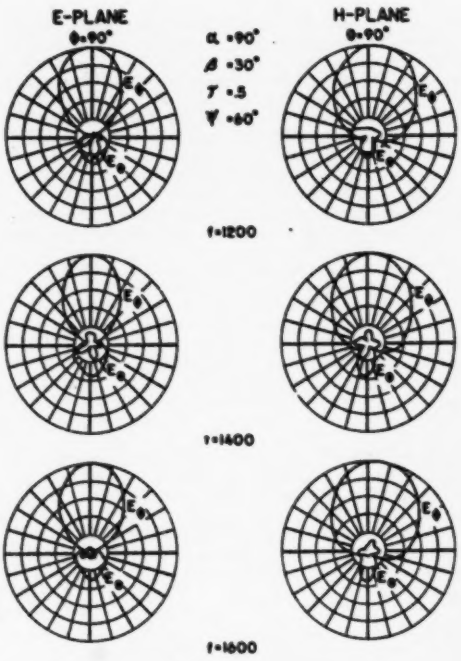


Fig. 5 Patterns for nonplanar (bent about horizontal axis) trapezoidal-tooth structure.

TABLE 1: VARIATION OF $Z_0$ AND VSWR WITH $\Psi$ ANGLE FOR A PRINTED, TRAPEZOIDAL TOOTH STRUCTURE

| $\Psi$ Angle | $Z_0$ | VSWR (Referred to $Z_0$) |
|---|---|---|
| 180 | 170 | 1.4 |
| 60 | 105 | 1.6 |

Table 1 shows how the impedance of this particular structure compared with the corresponding planar structure. The input impedance $Z_0$ was reduced from 170 ohms to about 105 ohms and the VSWR's referred to their respective input impedances were about the same. Thus, the impedance characteristic of a nonplanar trapezoidal tooth structure is considerably better than that of a curved tooth structure.

Another possible nonplanar structure is where the original planar structure is bent about its vertical axis to an included acute angle $\chi$. A structure of this type is shown in figure 6. Patterns and impedance were measured for a variation in $\chi$ from 180° to 60° in 30° steps. It was found that the E-plane patterns showed a definite tendency toward varying from bidirectional at $\chi = 180°$ to omnidirectional at $\chi = 60°$; the H-plane patterns remained bidirectional over the same range.

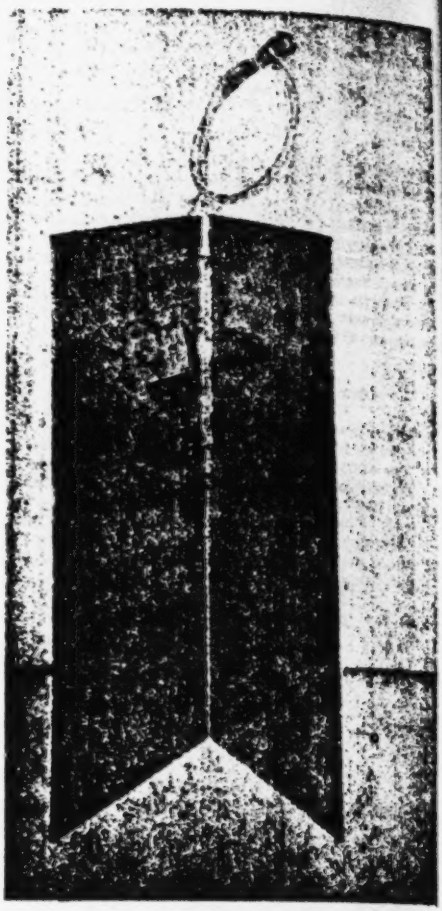

Fig. 6 A printed, nonplanar, trapezoidal-tooth structure bent about the Z axis.

Typical patterns for $\chi = 90°$ are shown in figure 7. In general, the patterns varied considerably with frequency.

TABLE 2: VARIATION OF $Z_0$ AND VSWR WITH VARIOUS X ANGLES FOR A PRINTED, TRAPEZOIDAL TOOTH STRUCTURE

| X Angle | $Z_0$ | VSWR (Referred to $Z_0$) |
|---|---|---|
| 180 | 170 | 1.4 |
| 120 | 180 | 1.35 |
| 90 | 200 | 1.4 |
| 60 | 210 | 1.9 |

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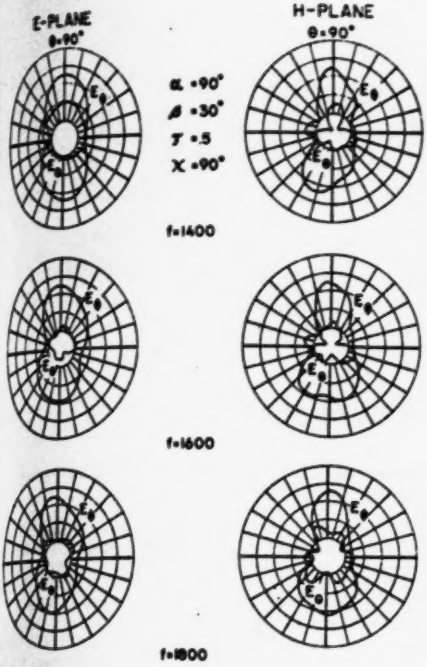



Fig. 7 Patterns for nonplanar (bent about vertical axis) trapezoidal-tooth structure.

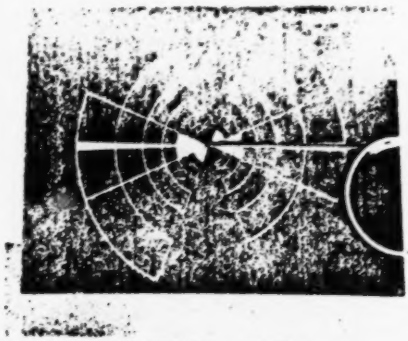
The variation of impedance with the angle χ was rather interesting, as can be seen in table 2. The average input impedance $Z_0$ increased as the χ angle was decreased. This was just the reverse of the effect that the reduction in $\psi$ produced.

## Wire Structures

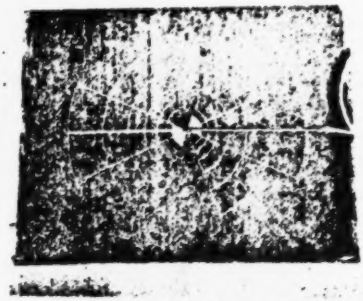
### Wire, Curved Tooth, Planar Structure

The approximation of sheet structures with wire structures was first investigated for a circular tooth structure. Two different approximations are shown in figure 8 and as can be seen, all the metal was removed except for narrow strips outlining the teeth. A still closer observation will indicate that the horizontal metal strips in figure 8a vary in width proportional to the distance from the center of the structure and the vertical members are triangular in shape. This is necessary in order to make the structure logarithmically periodic. Figure 8b is a structure identical to that of figure 8a, except that all members are of uniform width.

The average input impedance of the structure in figure 8b was slightly lower than that in figure 8a,



(a) With Tapered Elements



(b) With Uniform Elements

Fig. 8 Planar, printed, wire-like, circular-tooth structure.

110 ohms for figure 8b as compared to 150 ohms for figure 8a. As an interesting comparison, the impedance of a similar basic circular tooth structure was about 150 ohms.

In general, the patterns for the two cases were very similar. In both cases, the patterns were essentially independent of frequency, with the structure having tapered elements being slightly less frequency sensitive. The beamwidths in both the above cases were slightly wider than the beamwidth of the corresponding basic circular tooth structure.

### Nonplanar, Wire, Trapezoidal Tooth Structure

Since the circular tooth structures with only the outline of the teeth being made of metal performed almost as well as the basic circular tooth structure, this technique was used in constructing the trapezoidal tooth structures. In figures 9a and 9b are two typical types of wire, nonplanar, trapezoidal tooth structures. The only difference is that in figure 9a, the $\beta$ angle has

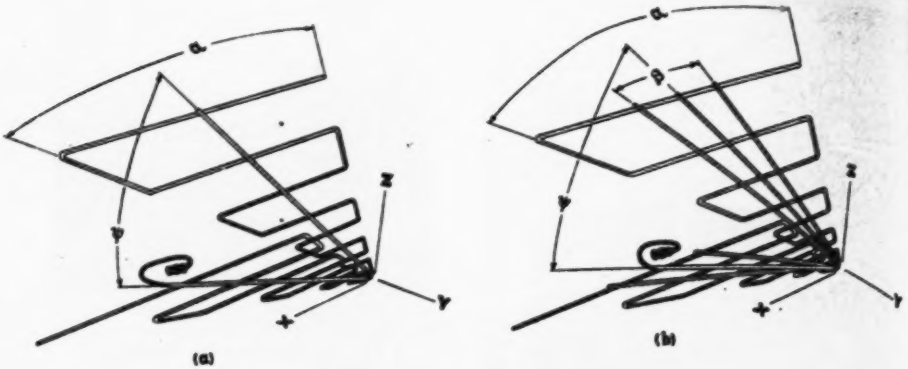



Fig. 9 Types of nonplanar, wire, trapezoidal-tooth structures.

been decreased to zero. Figure 10 is a photograph of a typical model used in the investigation of this type of structure. (In the photograph, the dielectric rod between the halves of the antenna was used for support only and is not part of the antenna.)

A considerable number of models of this type of structure with various values of the parameters $\alpha$, $\psi$, and $\tau$ were constructed and tested. In general, the patterns of these structures were quite independent of frequency, especially those with the larger values of $\tau$. Variations of the beamwidth of only several percent over a period of operation were common.

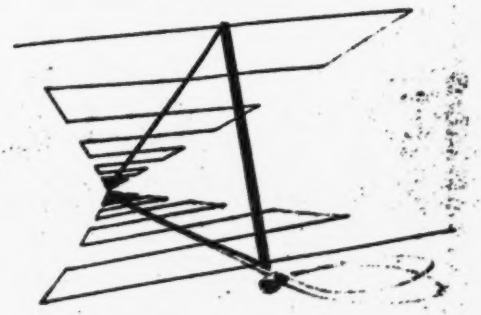


Fig. 10 A typical, wire, nonplanar, trapezoidal-tooth structure.

Figure 11 shows the patterns over a half-period for the antenna shown in figure 10. This particular antenna had an average E-plane beamwidth of 67°, an average H-plane beamwidth of 106° and an average front-to-back ratio of 15 db.

Table 3 shows how the beamwidth, gain, and front-to-back ratio are functions of the parameters of the antenna for several structures. From the table, it can be seen that both E-plane and H-plane beamwidths decrease as the design ratio of $\tau$ is increased. For example, take $\psi = 45°$, $\alpha = 60°$; then as $\tau$ was varied from 0.4 to 0.707, the E-plane beamwidth decreased from 86° to 64°, and the H-plane beamwidth decreased from 113° to 79°. It can then be concluded that if high gain is required, a large design ratio is desirable. It was found that the spacing between two adjacent transverse elements should not be greater than 0.3 of the length of the longer element. Otherwise, the pattern starts breaking up. Also, from the table it can be seen that the H-plane beamwidth increased with a decrease in $\psi$ angle for any one design ratio, while the E-plane pattern is essentially independent of the $\psi$ angle. Also, the front-to-back ratio, in general, increased with a decrease in $\psi$ angle. The $\alpha$ angle had a second-order effect on the beamwidth; with an increase in $\alpha$, a decrease in E-plane beamwidth and an increase in H-plane beamwidth resulted.

In using the information in table 3 to design an antenna with relatively high gain, high front-to-back ratio, not too great complexity (the number of elements increases as the design ratio increases), one must make a compromise as to what parameters to choose. For example, antenna number 14 has $\alpha = 60°$, $\beta = 0$, $\psi = 45°$, and $\tau = 0.6$. The gain is 6.5 db over a dipole and the front-to-back ratio is 15.8 db.

These pattern characteristics compare very favorably with those of a three-element Yagi antenna. Admittedly, this type of structure is somewhat more complex to construct than a Yagi, insofar as the number of elements required is greater, and it is necessary to use either a tapered coax line or a balanced open wire transmission line transformer in order to match the impedance of the structure to conventional transmission line. It has, however, the added advantage of having

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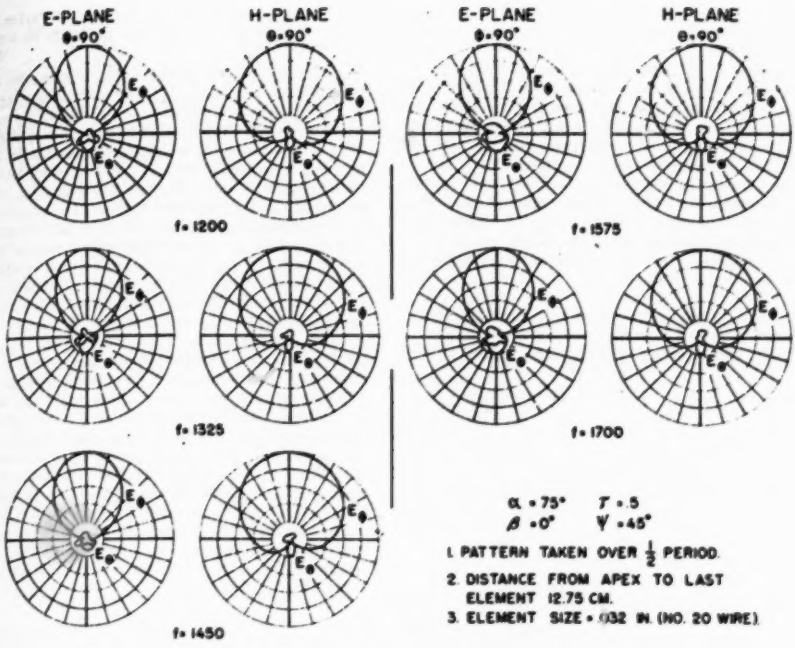


Fig. 11 Patterns for a typical, wire, nonplanar, trapezoidal-tooth structure.

TABLE 3. PATTERN CHARACTERISTICS FOR VARIOUS WIRE, TRAPEZOIDAL TOOTH STRUCTURES

| ANT | PARAMETERS α | γ | Ψ | AVE. HALF POWER BEAM WIDTHS IN DB E PLANE | H PLANE | APPROX. GAIN/DIPOLE IN DB | MAX. SIDE LOBE LEVELS IN DB |
|---|---|---|---|---|---|---|---|
| 1 | 75 | .4 | 30 | 74 | 155 | 3.5 | 12.4 |
| 2 | 75 | .4 | 45 | 72 | 125 | 4.5 | 11.4 |
| 3 | 75 | .4 | 60 | 73 | 103 | 5.3 | 8.6 |
| 4 | 60 | .4 | 30 | 85 | 153 | 3.0 | 12.0 |
| 5 | 60 | .4 | 45 | 86 | 112 | 4.2 | 8.6 |
| 6 | 60 | .4 | 60 | 87 | 87 | 5.3 | 7.0 |
| 8 | 75 | .5 | 30 | 66 | 126 | 4.9 | 17.0 |
| 9 | 75 | .5 | 45 | 67 | 106 | 5.6 | 14.9 |
| 10 | 75 | .5 | 60 | 68 | 93 | 6.1 | 12.75 |
| 11 | 60 | .5 | 30 | 70 | 118 | 4.9 | 17.7 |
| 12 | 60 | .5 | 45 | 71 | 95 | 5.8 | 14.0 |
| 13 | 60 | .5 | 60 | 71 | 77 | 6.7 | 9.9 |
| 14 | 60 | .6 | 45 | 67 | 85 | 6.5 | 15.8 |
| 15 | 60 | .707 | 45 | 64 | 79 | 7.0 | 15.8 |
| 16 | 45 | .707 | 45 | 66 | 66 | 7.7 | 12.3 |

essentially frequency independent impedance and pattern characteristics over a ten to one or more bandwidth.

The patterns of a larger antenna model, with the above design parameters (see figure 12) were measured over a ten to one frequency range (100 to 1000 mc). A slight increase in the beamwidths and a slight decrease in the front-to-back ratio was observed at about 300 mc. This effect was investigated by taking patterns of the structure and removing the elements one by one. It was found that the elements whose lengths were about 1.5 $\lambda$ were responsible for these pattern changes. Thus, some end effect was noticeable for this structure at a frequency approximately three times the low frequency limit of the antenna.

TABLE 4. VARIATION OF AVERAGE IMPEDANCE AND VSWR WITH $\psi$ ANGLE FOR A TYPICAL, WIRE, TRAPEZOIDAL TOOTH STRUCTURE

| $\psi$ Angle | $Z_o$ | VSWR (Referred to $Z_o$) |
|---|---|---|
| 60 | 120 | 1.4 |
| 45 | 110 | 1.45 |
| 30 | 105 | 1.5 |
| 7 | 65 | 1.8 |

Fig. 12 A larger model of a (low-frequency limit of about 100 mc) wire, nonplanar, trapezoidal-tooth structure.

Table 4 shows how the impedance varies with the $\psi$ angle for a typical wire, trapezoidal tooth structure.

The impedance of the wire, trapezoidal tooth structure (shown in figure 10) having the following parameters: $\alpha = 75°$, $\beta = 0$, $\tau = 0.5$, $\psi = 45°$, and $R_1 = 12.75$ inches, was measured over a sixteen to one frequency band (250 to 4000 mc). The impedance was good from 350 mc to 4000 mc or an eleven to one frequency band. This closely agrees with the previous definition of the low frequency limit since the width of the structure at the last element was 19.5 inches or a half wavelength at 304 mc. The actual measurements showed that the input impedance $Z_o$ decreased slowly and uniformly from about 150 ohms at 350 mc to about 75 ohms at the high end of the range of measurements. This change in input impedance is due to the modeling technique rather than a fault of the antenna. The elements of this particular model were of constant diameter (# 14 wire) and as the frequency was increased, the length-to-diameter ratio of the elements which were responsible for the radiation decreased. As further proof that modeling was partially responsible for this $Z_o$ change, the impedance of another larger model, figure 12, where the elements had been slightly tapered, was measured over a ten to one frequency range. Although the $Z_o$ of this structure also decreased as the frequency increased, the change was somewhat smaller. Thus, in order to obtain good frequency independence over a 10:1 bandwidth, it is necessary to model the structure accurately according to the design principles.

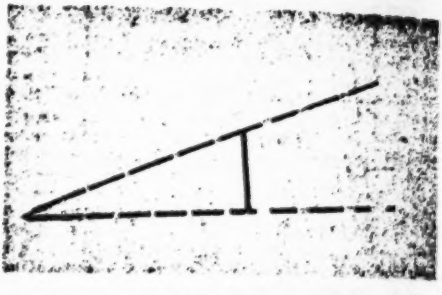

Fig. 13 A long (2$\lambda$ at 1,000 mc) nonplanar, wire, trapezoidal-tooth structure.

From the observed trends indicated in table 3, an antenna with relatively high gain was designed. The model was constructed as shown in figure 13. The parameters for this particular model were $\alpha = 14.5°$, $\beta = 0$, $\tau = 0.85$, $\psi = 29°$ and $R_1 = 60$ cm. In order to make the vertical spacing between horizontal elements of the same length of the two half-structures about twice the length of the particular elements, $\psi$ was set equal to 29°. $R_1$ was chosen equal to 60 cm in order to make the last element one half-wavelength long at 1000 mc. The patterns for this structure are shown in figure 14. The average E-plane beamwidth was 33°; the average H-plane beamwidth was 38°; and the front-to-back ratio was about 18 db. The resulting gain of this antenna then was slightly better than 10 db over a dipole, and the patterns were extremely frequency

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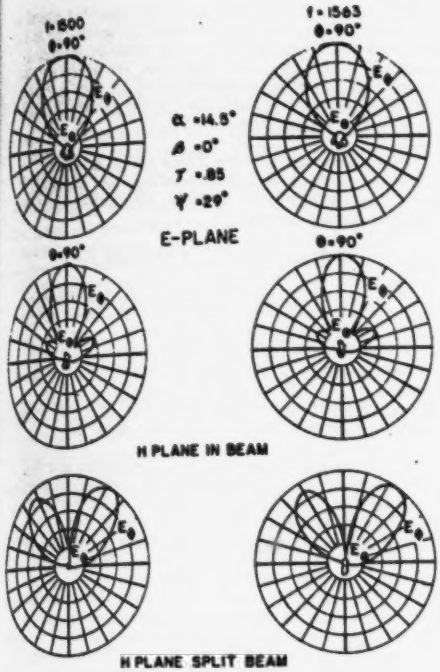


Fig. 14 Patterns for a long (2 λ at 1,000 mc) nonplanar, wire, trapezoidal-tooth structure.

independent. The H-plane split beam patterns of figure 14 were the result of turning one of the half-structures over 180°, i. e., one half-structure is then the mere image of the other. The same effect could be had by placing one of the half-structures over a ground plane at an angle $1/2\ \psi$ to the ground plane. It can be seen that the ground plane would divide the structure symmetrically. The double lobes appear at about ± 35° from this plane of symmetry.

On the shorter structures, where the spacing between the half-structure and the ground plane was small, that is, much less than a half-wavelength, the effect of the ground plane caused the impedance to rotate around the center of a Smith chart in a periodic manner, but at a VSWR of five to eight, which is very undesirable. However, this long structure had impedance characteristics very similar to a structure in free space, with the $Z_0$ being only one-half the $Z_0$ of an antenna in free space. The actual $Z_0$ was 80 ohms with a VSWR of 1.1:1 over a period.

## Wire Triangular Tooth Structures

Another step toward simplifying the construction of these logarithmically periodic structures was the triangular tooth or "Zig-Zag" structure illustrated in

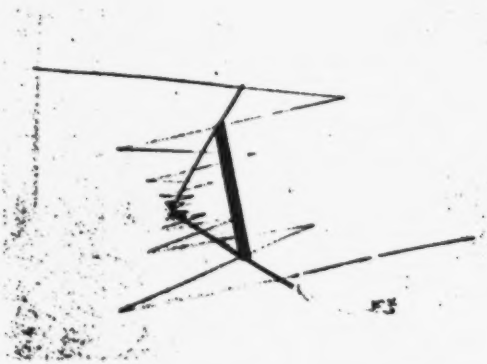

Fig. 15 A typical, wire, nonplanar, triangular-tooth structure.

figure 15. It has the same parameters as the trapezoidal tooth structure of figure 10. Figure 16 shows typical patterns for this triangular tooth structure. In general, the pattern characteristics are a slight improvement over those of the trapezoidal tooth structure. The average E-plane beamwidth was 70° as compared to 67°; the average H-plane beamwidth was 89° as compared to 106°; and the front-to-back ratio was 14.4 db as compared to 14.9 db for the trapezoidal tooth structure. The impedance for the triangular tooth structure was slightly lower (100 ohms with a VSWR of 1.5 over the frequency range compared) than that of the trapezoidal tooth structure.

Another model of the triangular tooth structure was constructed similar to antenna 14 in table 3 ($\alpha$ = 45°, $\beta$ = 0, $\tau$ = 0.707 and $\psi$ = 45°). As before, the H-plane beamwidth was slightly narrower, the E-plane beamwidth was about the same, and the front-to-back ratio was slightly greater than that of the similar trapezoidal tooth structure.

## Phase Rotation Principle

The phase rotation phenomenon is a basic characteristic of these logarithmically periodic structures and has been verified experimentally. It can best be explained in the following manner: if one of these structures is fed, and if the phase of the electric field received at a distant dipole (see figure 2) is measured relative to the phase of current at the feed point of the structure, the phase of the received signal will advance 360° as the structure is shrunk through a period. Or,

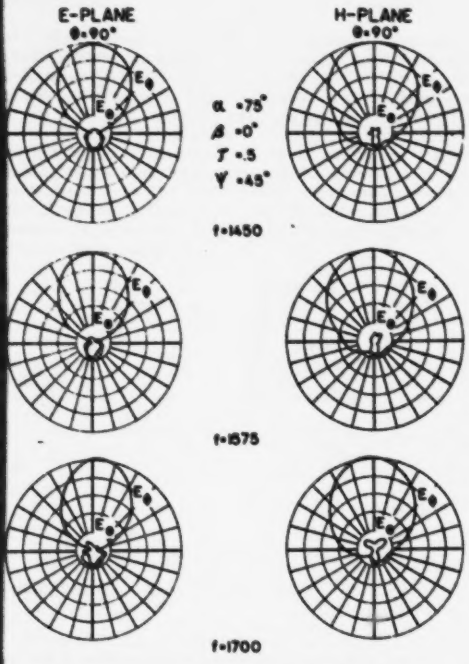


Fig. 16 Patterns for nonplanar, wire, triangular-tooth structure.

in other words, if the frequency of the exciting signal is increased by a period, and the phase is measured at the dipole while keeping the dipole at a constant electrical distance from the periodic structure, the phase will be delayed 360°, relative to the phase of the feed current. This characteristic is analagous to the pattern relation principle[2] of angular structures.

This phenomenon is the factor which makes it possible to achieve the omnidirectional and circularly polarized logarithmically periodic structures discussed in the following sections.

## Omnidirectional Structures

Often it is desirable to have a wide band antenna that gives omnidirectional patterns. The most common antenna to date that tends to meet such a requirement is the vertically polarized discone or biconical antenna. However, pattern breakup limits the bandwidth of these antennas to 2 or 3 to 1. The desirability of designing a logarithmically periodic structure with omnidirectional characteristics is readily apparent.

Since two dipoles arranged in a turnstile and ninety degrees out of phase give omnidirectional patterns, it was decided to arrange two planar, sheet metal structures (which have approximate dipole patterns) in a turnstile as shown in figure 17a. Since the planar sheets were actually soldered together where they crossed, it is obvious that the two sheet structures could not be identical or the same result would occur as when feeding two crossed dipoles in phase (a bidirectional pattern with maximum lobes occurring at an angle of 45°). Therefore, one of the structures was made $\tau^{\frac{1}{2N}}$ times the size of the other (where N is the number of arms of the structure) in order to obtain the 90° phasing.

An easy way to visualize such a structure is to imagine two cones placed apex to apex on a common

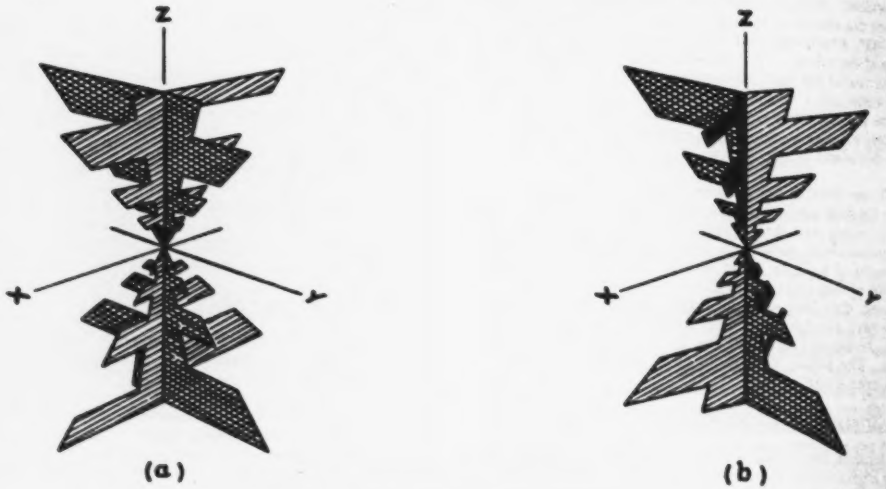


Fig. 17 Types of omnidirectional structures.

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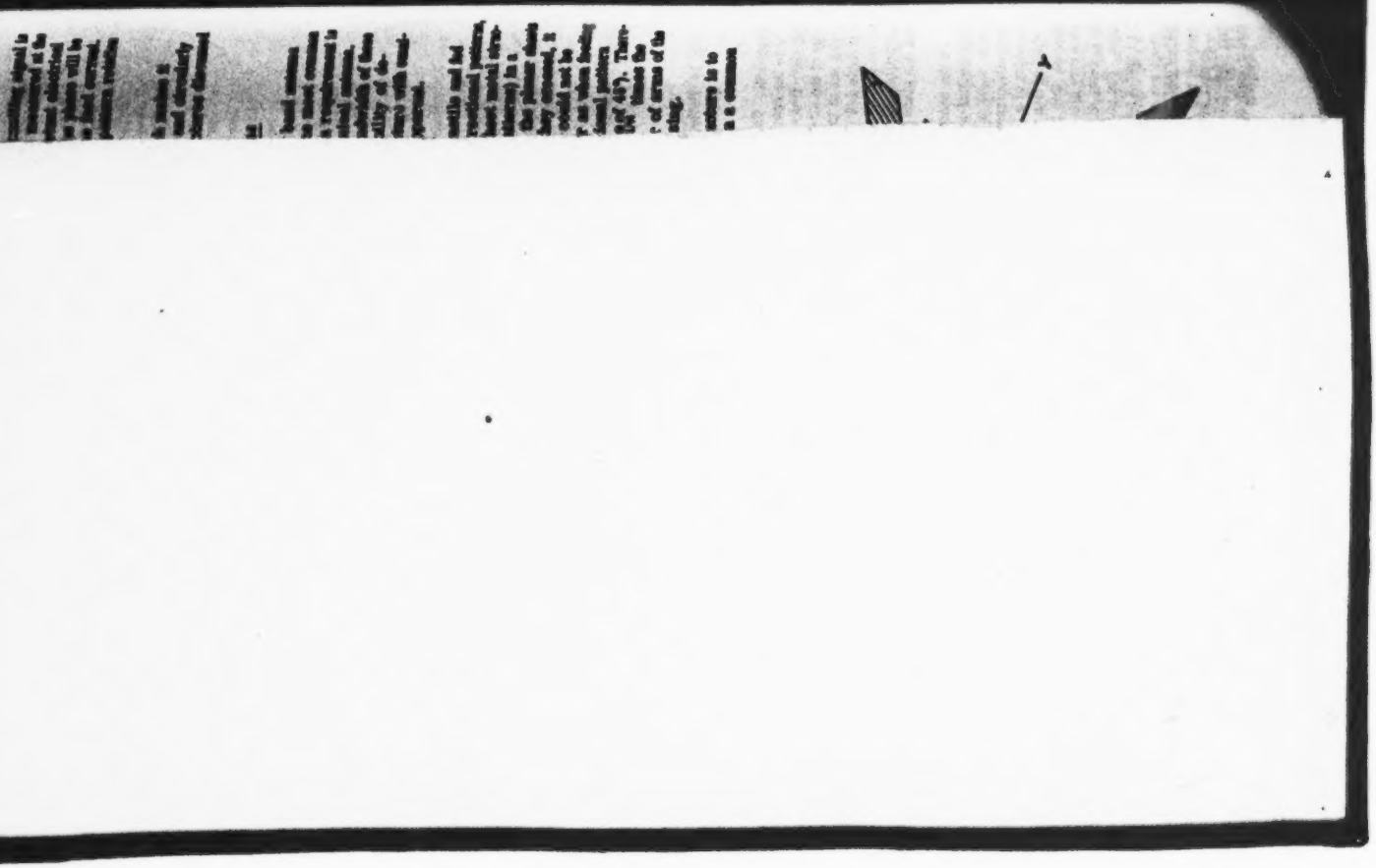

axis. Starting at the apex of each cone, an equiangular spiral is placed on the slant side of the cone with the axis of the spiral coinciding with the axis of the cone. The spiral on one cone is made to rotate clockwise; the spiral on the other cone is made to rotate counterclockwise as the two cones are viewed simultaneously from the point where their respective apexes meet. Actually, these spirals are the openings of grooves which become progressively wider and deeper as they spiral away from the apexes of the cones. The outlines of four arms of a four-arm structure would be the lines of intersection of the cones and two planes perpendicular to each other and intersecting on the axis of the cones. When the cone concept is used, it is possible to visualize a number of different structures. Figure 17b is an example of a structure with three arms.

Figure 18 is a photograph of a circular tooth structure constructed as stated above. The design ratio $\tau$ of this particular structure is 0.7. Of the various structures constructed and tested, it was found that the structure with a design ratio of 0.5 had the best pattern characteristics. Typical patterns of this structure are shown in figure 19. The $\theta$ = 90°, $\phi$ variable patterns are omnidirectional within ±1.5 db over the frequency range of one period; the $\phi$ = 90°, $\theta$ variable patterns are bidirectional and have an average beamwidth of about 65°. The characteristic impedance was 100 ohms with a normalized VSWR of 1.2 to 1.

Fig. 18 A typical, four - armed, sheet, circular - tooth, omnidirectional structure.

A limited investigation of the effect of varying the $\alpha$ angle while holding $\beta$ fixed at 45° for a structure having a design ratio of 0.7 (figure 18) was made. As $\alpha$ was reduced from 135° to 115°, the E-plane patterns were unchanged while the H-plane beamwidth increased slightly from 68° to 75°. When $\alpha$ was reduced to 95°, the E-plane pattern was omnidirectional within ±3 db, and the H-plane pattern beamwidths were about 90°. The impedance did not change appreciably as $\alpha$ was reduced.

The trapezoidal tooth structure shown in figure 17b ($\alpha$ = 90°, $\beta$ = 30°, $\tau$ = 0.5) did not have as uniform

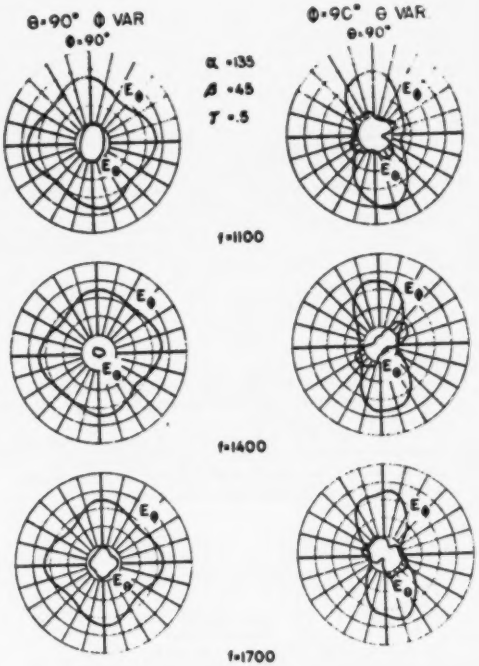


Fig. 19 Patterns for omnidirectional curved - tooth structure.

or as frequency independent omnidirectional characteristics as did the similar circular tooth structure. As a comparison, the trapezoidal tooth structure was omnidirectional within ±2.1 db as compared to ±1.5 db for the circular tooth structure; and the H-plane, bidirectional patterns were on an average 55° as compared to 65°. The impedance was 140 ohms and 100 ohms for the trapezoidal and circular tooth structures, respectively. Both had a normalized VSWR of 1.2 to 1.

The only other type of sheet metal omnidirectional structure tested was a three-armed circular tooth structure (see figure 17b for a similar trapezoidal tooth structure). The structure was omnidirectional within ±3 db and the patterns were more frequency dependent than the structure having four arms. It appears that the more arms a structure has (within reason), the more omnidirectional it will be.

One wire, trapezoidal tooth, omnidirectional structure was constructed and tested (see figure 20). The E-plane patterns varied somewhat in their omnidirectional characteristics with frequency, but on an average, they were omnidirectional within ±2.1 db; the H-plane patterns were bidirectional with an average beamwidth of 60°. The input impedance was 135 ohms with a normalized VSWR of 1.3 to 1. In view of the relative simplicity, this structure could be used as an hf antenna. The wire structure could be easily strung up between four wooden poles.

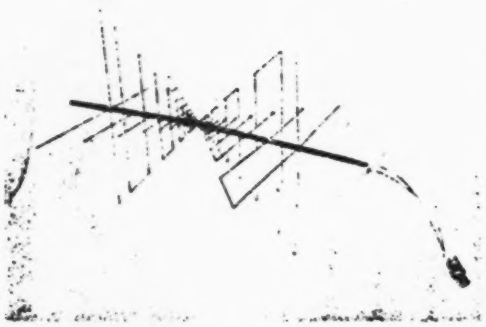

Fig. 20 A typical, four-armed, wire, trapezoidal-tooth, omnidirectional structure.

Unfortunately, it is not possible to use one-half of any of the above structures over a ground plane (and fed against the ground plane) without having large variations of pattern and impedance over a period of frequency.

## Circularly Polarized Antennas

A limited investigation of circularly polarized, unidirectional logarithmically periodic broadband structures was performed. The most successful of the various techniques tried was that of taking the planar structure shown in figure 21 and placing the quarter-structures, one on each slant side of a pyramid. The angle between opposite slant sides of the pyramid is the $\psi$ angle of the structure.

As can be observed from the figure, one structure is $\tau^{1/4}$ the size of the other. A very well-defined circularly polarized beam (at $\phi = 90°$, $\theta = 90°$) is obtained. The enlarged view of the feed point shows that, in general, two adjacent quarter-structures are fed against the remaining two quarter-structures; two and three are being fed against four and one. The sense of the circular polarization can be reversed by simply switching the feed point, or by feeding three and four against one and two.

Four experimental patterns over approximately a half-period are shown in figure 22. As can be seen, the axial ratio r as measured on the beam axis varied from 1.05 to 2 over this range. Since the patterns for the linearly polarized components ($E_\phi$ and $E_\theta$) are very similar, it is expected that good circular polarization is obtained over most of the beam.

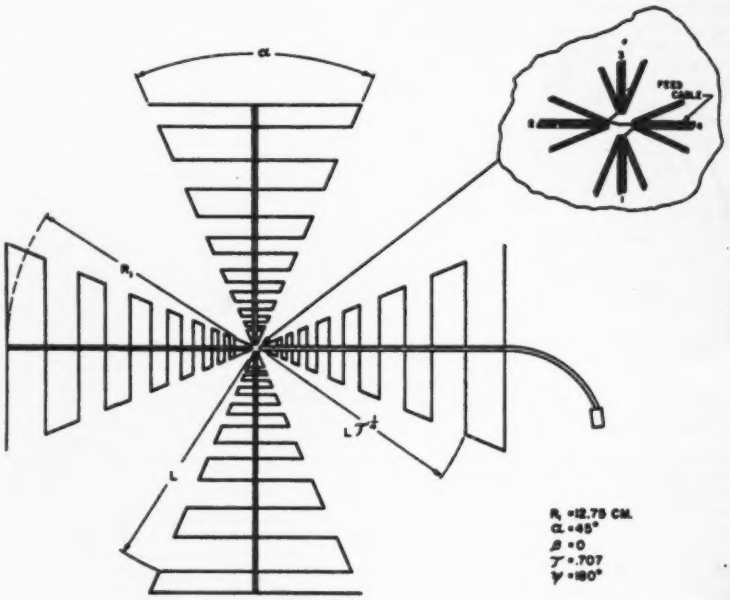


Fig. 21 Wire, trapezoidal-tooth, circular-polarized structure.

Fig. 22 XY plane
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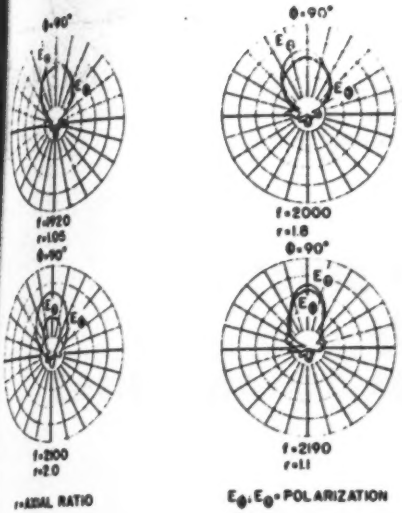


*Fig. 12* XY plane patterns of circular-polarized pyramidal structure.

## Current Distribution Measurements

An attempt was made to measure the magnitude and phase of the currents flowing on the elements of a typical nonplanar, wire, trapezoidal tooth structure. The current distribution was very complex and the results were not too conclusive. However, it was observed that, as the magnitude of the currents was measured from the vertex out toward the longer transverse elements, a point of maximum current magnitude was reached. From this point, the magnitude of the current decreased to more than 30 db below its value at the maximum point. The transverse elements at this low current point were much longer than a half wavelength of the operating frequency. This tends to demonstrate that end effects are negligible on these structures, which must be the case for wide band operation. As would be expected, the point of maximum current magnitude shifted toward the vertex of the structure as the frequency was increased.

## Conclusions

Many types of logarithmically periodic antenna structures have been built and tested. Most of those which gave essentially frequency independent [illegible] have been reported here but there were many [illegible] for which the pattern and/or impedance were quite frequency sensitive. Unfortunately, no theory has been established which even predicts the types of structures which will give frequency independent operation. The equicomplementary condition (for planar structures) is sufficient to insure frequency independent impedance but not patterns. All of the planar structures (even those that don't work) may be considered as cross sections of frequency independent three-dimensional angular structures so that this approach leads nowhere. Thus, it is felt that a theoretical investigation of this class of antennas would be most fruitful.

Nevertheless, a small amount of effort has led to the discovery of structures which give a wide variety of essentially frequency independent radiation characteristics over practically unlimited bandwidths. One of many possible applications is for flush-mounted microwave antennas. Here, unidirectional structures can be placed in cavities with the cavity having little influence on the electrical characteristics because of the unidirectional pattern.

## Acknowledgment

Special thanks are due Dr. R. L. McCreary for his support and tolerance and to Forrest G. Arnold who constructed and tested many of the models.

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Report No. 1

Paul E. Mayes

ANTENNA LABORATORY

Quarterly Engineering Report

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
ENDANT EX. NO. 7
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

# RESEARCH STUDIES ON PROBLEMS RELATED TO ANTENNAS

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Project No. 9-(13-6278) Task 40572
WRIGHT AIR DEVELOPMENT CENTER

ELECTRICAL ENGINEERING RESEARCH LABORATORY
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

# QUARTERLY ENGINEERING REPORT
# ON
# RESEARCH STUDIES ON PROBLEMS
# RELATED TO ECM ANTENNAS

Contract No. AF33(616)-6079
Project No. 9-(15-4600) Task 40572
Report No. 1

WRIGHT AIR DEVELOPMENT CENTER

30 January 1959

Report for the Period:

1 September 1958

to

1 December 1958

Approved by:

George Deschamps

G.A. Deschamps
Professor

P.E. Mayes
Associate Professor

Antenna Section
Electrical Engineering Research Laboratory
Engineering Experiment Station
University of Illinois
Urbana, Illinois

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# 1. NUMERICAL CALCULATIONS OF SPIRAL ANTENNA FIELDS

## 1.1 Purpose

The purpose of this investigation is to make numerical calculations of the fields produced by the equiangular spiral antenna.

## 1.2 Factual Data

1.2.1 Research Staff - P.E. Mast and T.M. Lahey

1.2.2 Status

A theoretical method for determining the fields produced by the equiangular spiral antenna was given in Technical Report No. 35. A program has been started to investigate the feasibility of making numerical caculations from these theoretical results. The easiest calculation of practical value seems to be the calculation of the voltage across the gap between the antenna arms for the special case when the gap is small.

The numerical calculations are complicated by the repeated occurance of gamma functions of complex argument, Bessel functions of complex order, and associated Legendre functions of complex degree. At the present time sub-routines for an ILLIAC program have been completed and tested for handling complex arithmetic, and for the generation of the gamma functions of complex argument. The gamma function sub-routine generates them in a form convenient for use in the other calculations, and give values correct to seven decimal places.

## 1.3 Plans for the Next Interval

It is planned to program a sub-routine for the generation of associated Legendre functions of complex degree.

# 2. LOG PERIODIC ANTENNA STRUCTURES

## 2.1 Purpose

The objective of this work is to develop design techniques for broad band antennas.

## 2.2 Partial Data

2.2.1 Research Staff - D. Isbell

2.2.2 Status

Professor Deschamps has formulated a generalization of Babinet's

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principle to include multiterminal structures. The experimental results which have been obtained for the multielement log periodic antennas are found to be predictable in terms of his analysis. A point of particular significance is that it is theoretically possible to design a radiating structure to have an impedance which is not only independent of frequency but of any predetermined value limited only by the number of elements originating at the feed point. This theory will be published in a forthcoming report.

Measurement of the input impedance and a brief radiation pattern investigation of the multielement log periodic structures of as many as seven elements has been concluded and these results will be included in a technical report on the subject.

2.3 Plans for Next Interval

An investigation of log periodic structures of thin linear elements (zero tooth width) is planned.

## 3. INTERSATELLITE FERRET ANTANNAS

3.1 Purpose

The objective of this work is to obtain a number of exact analytical solutions for the patterns and impedance of large antennas whose bounding surfaces are spheriods and cones. These solutions will serve as guides in the design of satellite antennas with special characteristics, for example those with essentially spherical coverage.

3.2 Factual Data

3.2.1 Research Staff: P.E. Mayes, W.L. Weeks

3.2.1 Status

The radiation patterns of a spherical antenna, approximately nine wavelengths in diameter, excited by an annular slot located near one of the poles have been calculated. The effect on the patterns of different slot sizes (diameters in the range .1λ to 1.5λ) and of various dielectric coatings has been studied.

A systematic investigation into certain aspects of the problem of digital computation of spheroidal wave functions has been made. This study has revealed, for example, that the problem of eigenvalue determination is much less time consuming than had been expected. The results of

Report No. 2

ANTENNA LABORATORY

Quarterly Engineering Report

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 5
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

# RESEARCH STUDIES ON PROBLEMS RELATED TO ECM ANTENNAS

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO.
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

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Project No. 9-(13-6278) Task 40572

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# QUARTERLY ENGINEERING REPORT
# ON
# RESEARCH STUDIES ON PROBLEMS
# RELATED TO ECM ANTENNAS

Contract No. AF33(616)-6079
Project No. 9-(13-4600) Task 40572
Report No. 2

WRIGHT AIR DEVELOPMENT CENTER

31 March 1959

Report for the Period:

1 December 1958

to

1 March 1959

Approved by:

G. A. Deschamps
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P. E. Mayes
Associate Professor

Antenna Section
Electrical Engineering Research Laboratory
Engineering Experiment Station
University of Illinois
Urbana, Illinois

# 2. LOG-PERIODIC ANTENNA STRUCTURES

## 2.1 Purpose

## 2.2 Factual Data

### 2.2.1 Research Staff - D. Isbell

### 2.2.2 Status

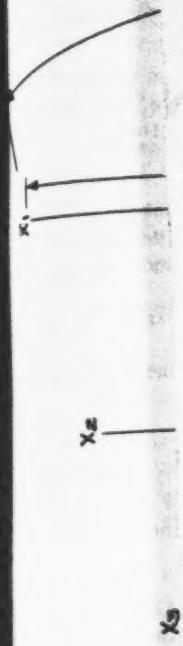
A new type of log-periodic antenna is presently being investigated. This antenna is made up of a coplanar array of conventional thin linear dipole elements as shown in Figure 1. The structure is defined in terms of the ratio of periodicity $\tau$ and the angle $\alpha$. The elements are oriented with respect to the feeder so that an additional $\pi$ radians is added to the phase of the current at the terminals of each dipole element. This is shown schematically in Figure 1 as a crossover in the feeder between each element.

Preliminary pattern and impedance measurements have shown that this structure should provide broadband performance comparable to that of the solid sheet, broad tooth, log-periodic antennas. The characteristic radiation pattern is end fire in the negative x direction.

It is hoped that this antenna, by virtue of its relatively simple components, will aid in providing a better understanding of log-periodic antennas in general. Analysis may be found possible in terms of the self and mutual impedances of the individual dipoles of the array.

## 2.3 Plans for Next Interval

A program of pattern and impedance measurements is planned to provide complete information for several values of $\tau$ and $\alpha$.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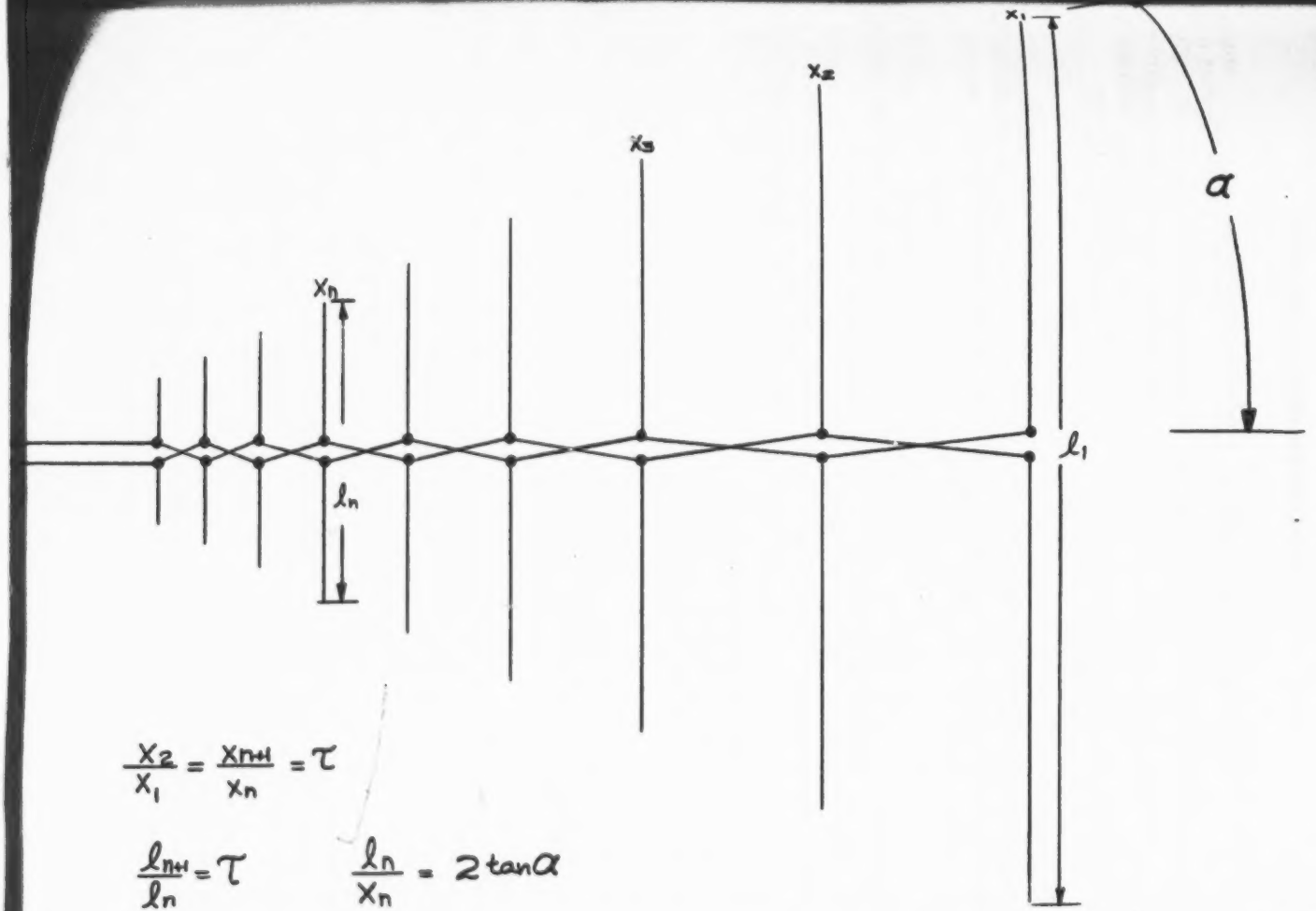


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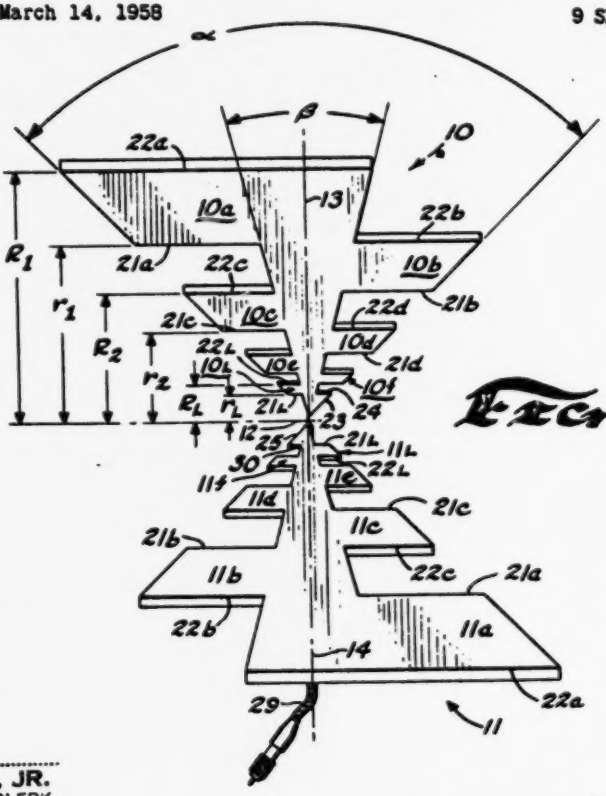


FIG 1

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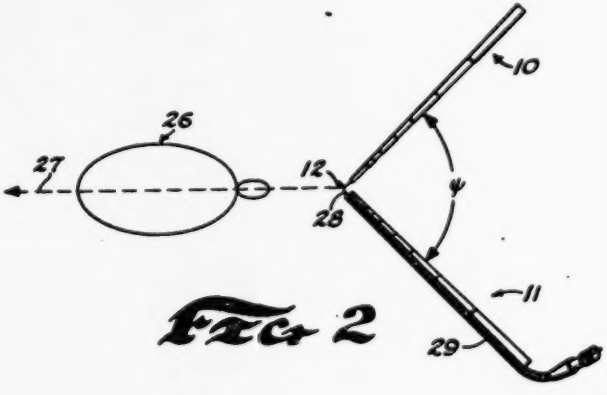


FIG 2

510

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LOGARITHMICALLY PERIODIC ROD ANTENNA

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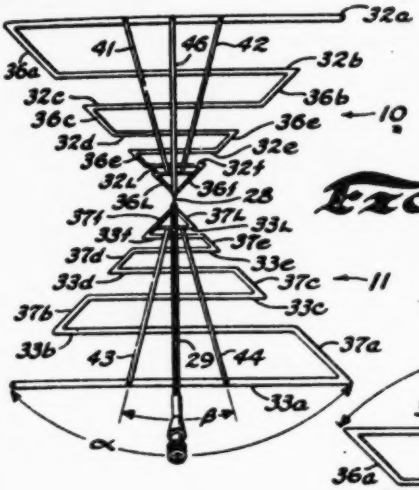
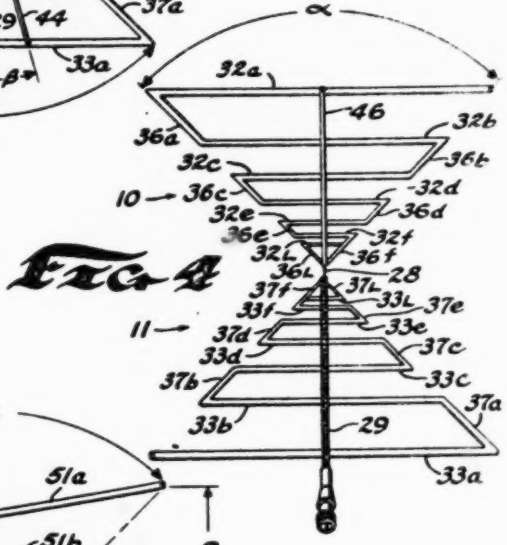



Fig. 3

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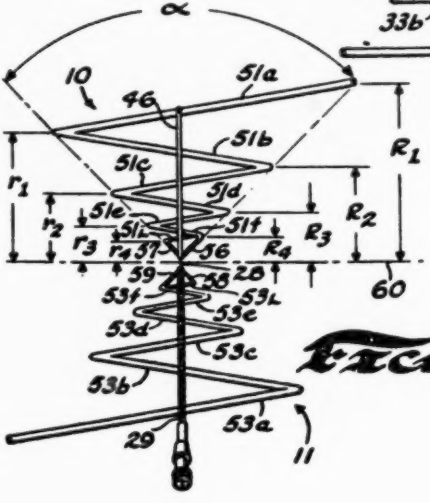


Fig. 5

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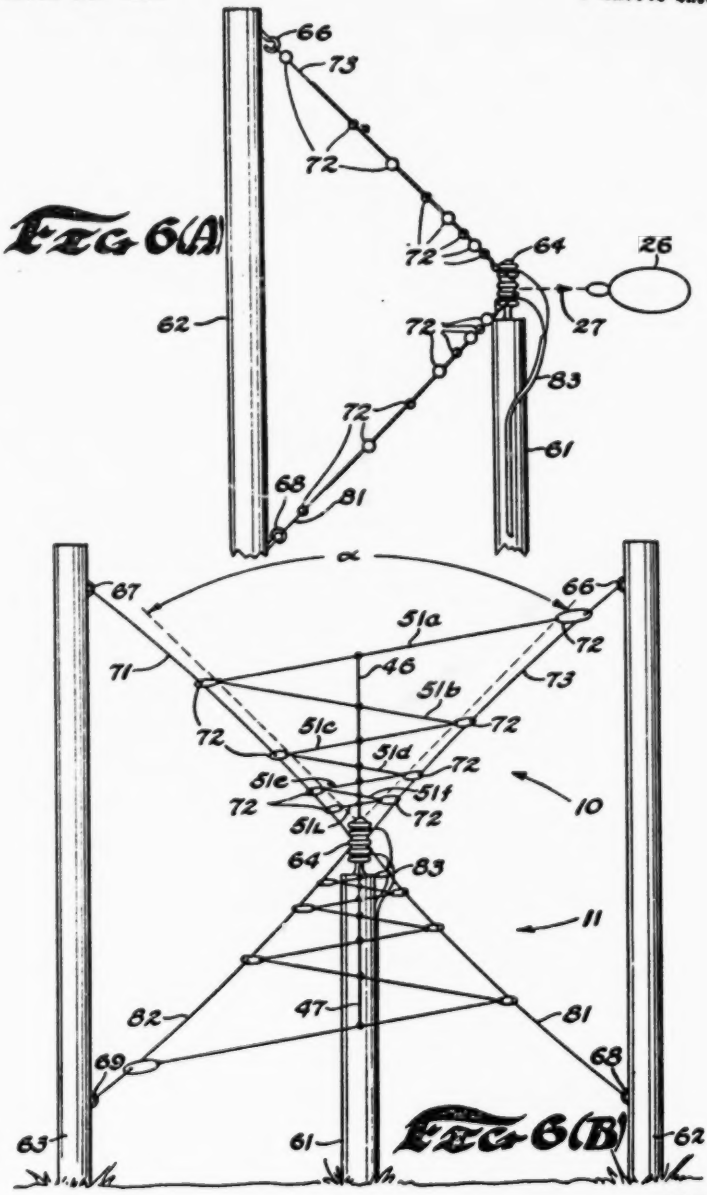


FIG 6(A)

FIG 6(B)

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# LOGARITHMICALLY PERIODIC ROD ANTENNA

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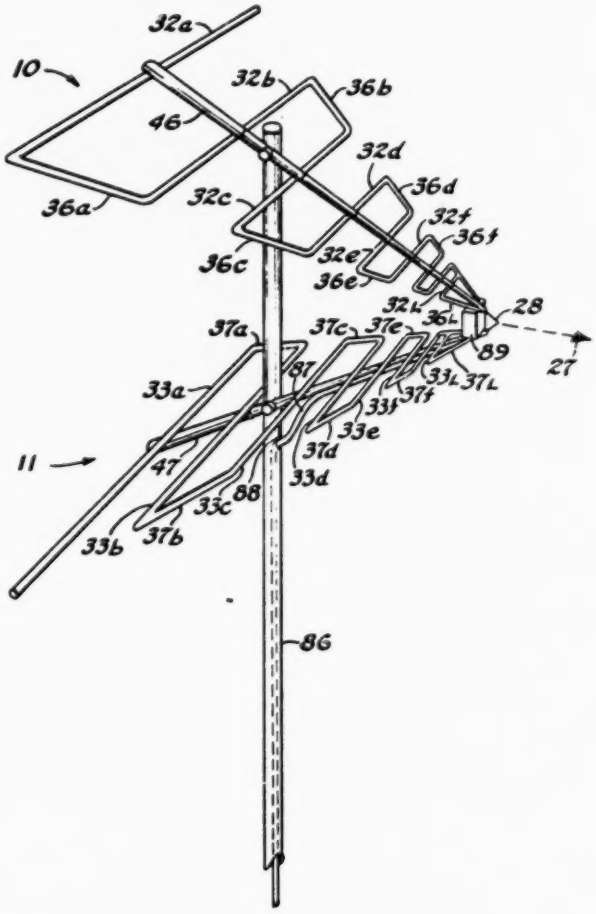
FIG. 7

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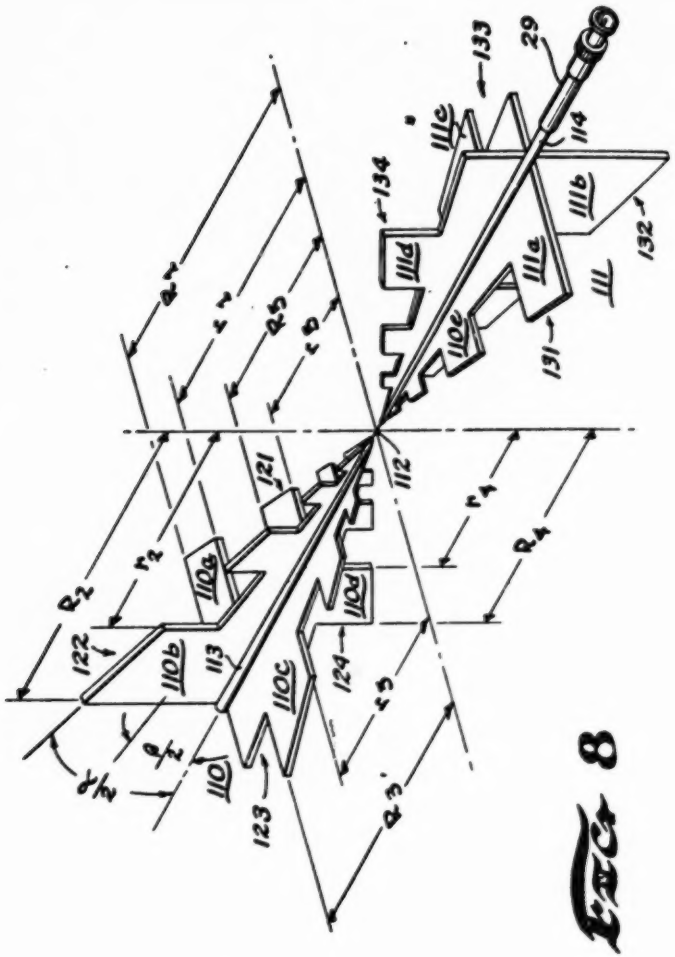


FIG. 8

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LOGARITHMICALLY PERIODIC ROD ANTENNA

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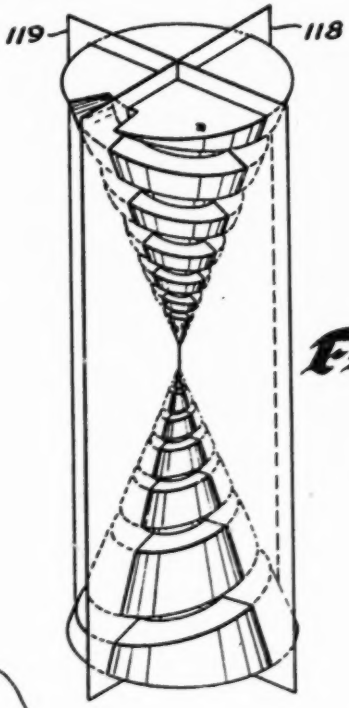


FIG 9

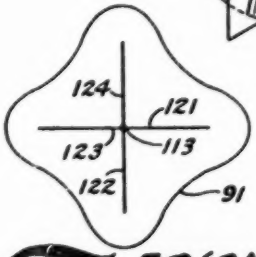


FIG 10(A)

FIG 10(B)

FIG 10(C)

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Feb. 26, 1963 R. H. DU HAMEL ET AL 3,079,602

LOGARITHMICALLY PERIODIC ROD ANTENNA

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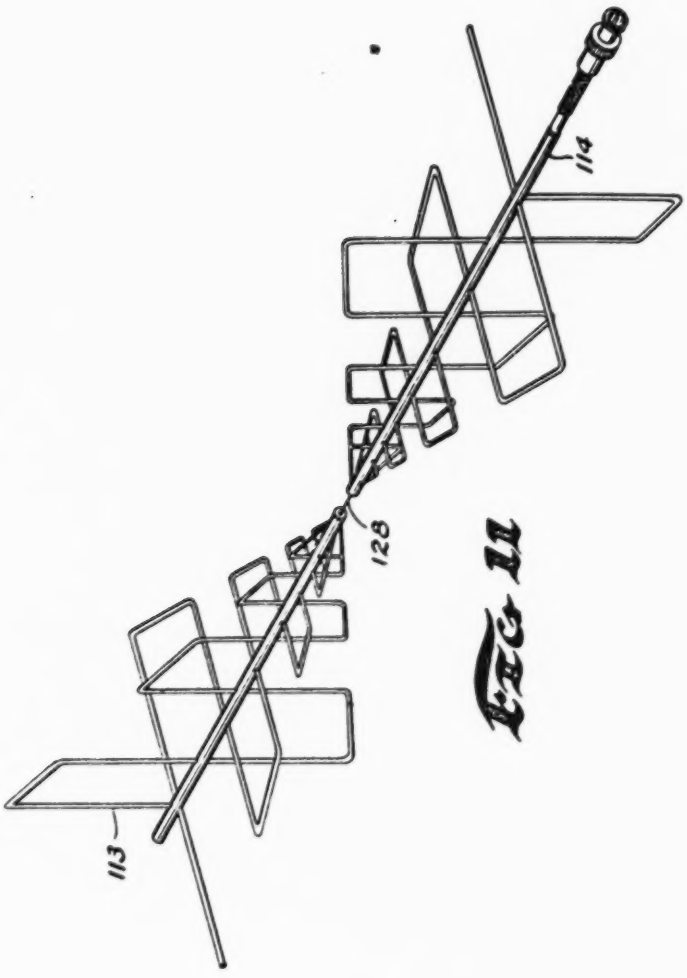


Fig 11

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LOGARITHMICALLY PERIODIC ROD ANTENNA

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FIG 12

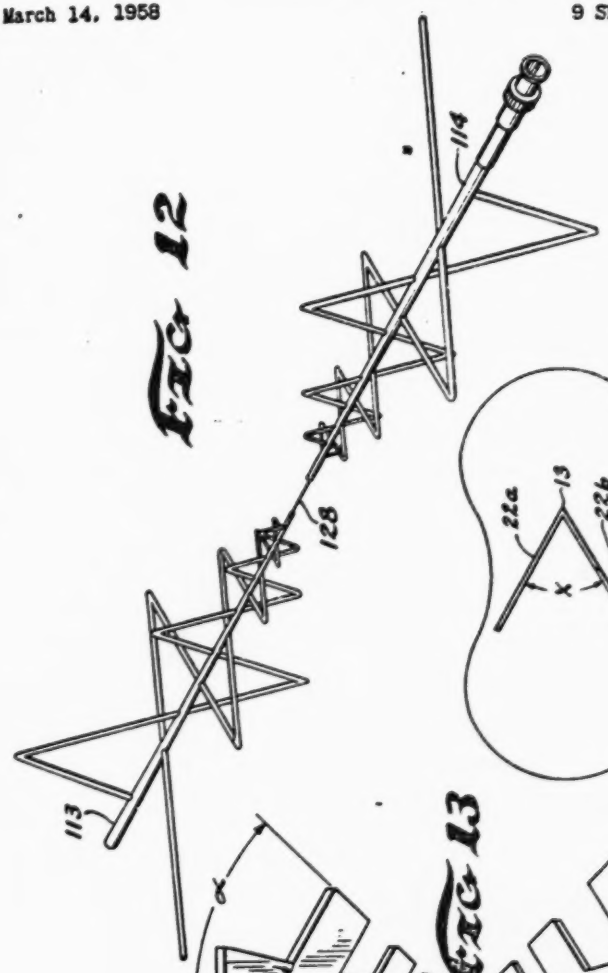



FIG 16

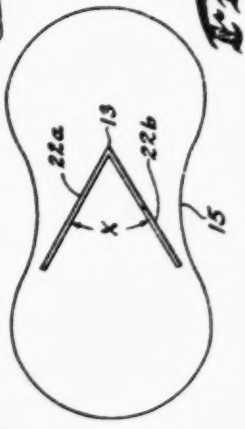
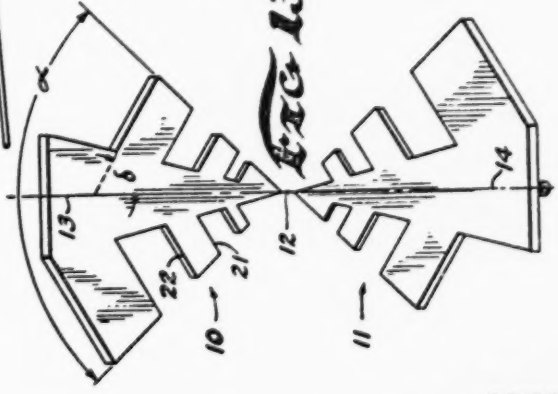



FIG 13

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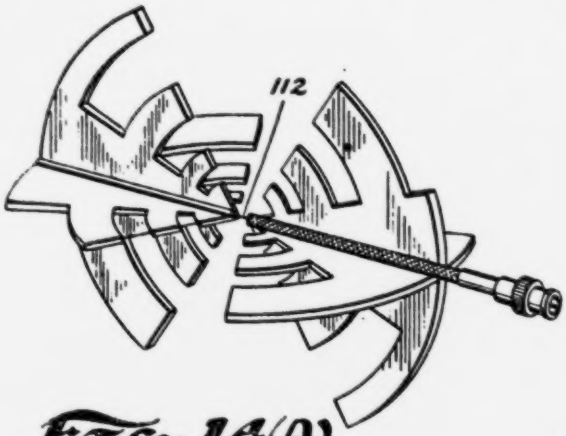


FIG 14(A)

FIG 14(B)

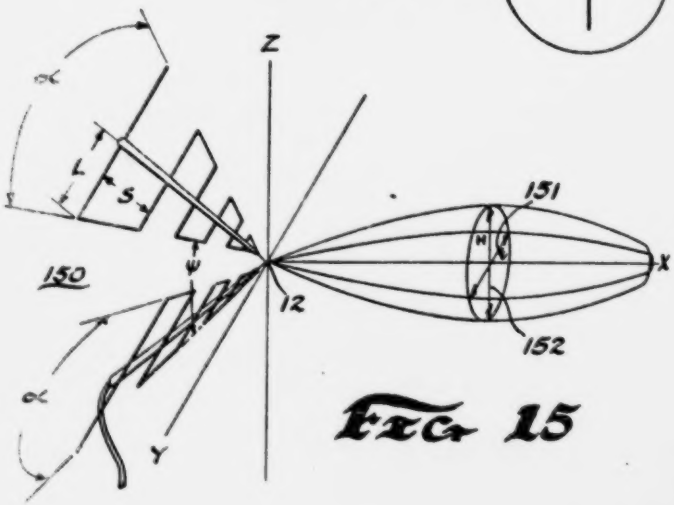


FIG 15

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United States Patent Office 3,079,602 Patented Feb. 26, 1963



3,079,602

# LOGARITHMICALLY PERIODIC ROD ANTENNA

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14 Claims. (Cl. 343—968)

This invention relates to antennas of a type that can be described as logarithmically periodic, since their structure is repetitive in a logarithmic manner. Such antennas are particularly useful because they are capable of maintaining substantially-fixed radiation patterns and input impedances over a very broad frequency range, which may be greater than ten-to-one.

The general subject of such antennas is treated in a paper by R. H. DuHamel and D. E. Isbell, titled "Broadband Logarithmically Periodic Antenna Structures" and is found in the 1957 I.R.E. National Convention Record, Part I, of the group on Antennas and Propagation, Microwave Theory and Techniques. This article is only concerned with planar logarithmically periodic antennas which comply with the complementary principle when they are infinitely extended. The complementary principle requires that the same form be obtained when the antenna structure is interchanged with the planar space surrounding it. That is, the complementary principle requires that when an antenna and its complement are added together a complete infinite screen is obtained. In many situations, if an antenna has a complementary shape, it may be rotated by 90° about its center, and it will fill the area previously existing between its elements. If an antenna is identical to its principle it has a constant impedance of $60\pi$ ohms which is independent of frequency. This is explained in an article by V. H. Rumsey titled "Frequency Independent Antenna" found in the same I.R.E. records as the first-mentioned article. It was previously believed that the complementary principle must be adhered to in order to obtain a constant antenna input impedance independent of frequency.

The present invention deviates from the complementary principle in several ways and yet is able to maintain a radiation pattern and input impedance that are very nearly independent of frequency over a very broad range. For example, antenna structures made according to this invention need not lie in a single plane, which is a requirement of the complementary principle. Furthermore, when a form of the invention is made to lie in a single plane, it need not satisfy the complementary principle. The invention teaches how a logarithmically periodic antenna structure can be made entirely with a straight-lined configuration.

The invention provides a structure that is logarithmically periodic from a given vertex point. As a consequence, similar portions of the antenna repeat with a geometric-progression relationship as a function of their distance from the vertex. Transverse construction lines in the invention can be made linear to permit substantial structural simplifications, particularly for large sized antennas to extend their range to relatively low frequencies.

Some of the objects of this invention are the following:

To provide an antenna which maintains the same radiation pattern throughout an extremely large operating frequency range;

To provide an antenna which maintains a very-nearly constant input impedance over an extremely large frequency range;

To provide a logarithmically periodic antenna with a radiation pattern that can be made omnidirectional;

To provide a logarithmically periodic antenna with a radiation pattern that is controllably asymmetric;



To provide logarithmically periodic antennas having structural simplicity, while permitting frequency independence of radiation pattern and input frequency over extremely broad frequency ranges; and

To provide a logarithmically periodic antenna which can be entirely made of straight-lined structure, capable of easy fabrication from wire or rods.

Further objects, features and advantages of the invention will become apparent to a person skilled in the art upon further study of the specification and accompanying drawings, in which:

FIGURE 1 illustrates an elevational view of one form of the invention;

FIGURE 2 shows a side view and radiation pattern;

FIGURES 3, 4, 5, 6(A), 6(B) and 7 represent other forms of the invention;

FIGURE 8 is a perspective of a three-dimensional form of the invention;

FIGURE 9 illustrates a conical development of the three-dimensional form in FIGURE 8;

FIGURES 10(A), (B) and (C) show end views of various forms of the invention with their radiation patterns;

FIGURES 11 and 12 show perspectives of other three-dimensional forms of the invention;

FIGURE 13 provides a modification of the invention;

FIGURES 14(A) and (B) respectively illustrate a rounded-tooth three-dimensional form, and its end view and radiation pattern;

FIGURE 15 represents a radiation pattern; and

FIGURE 16 shows an end view of a center-line folded antenna.

Now referring to detailed forms of the invention, FIGURE 1 is first considered. It shows a back-elevational view of an antenna made from a pair of metal sheets having a thickness that tapers toward a terminal point 12. FIGURE 2 shows a side view of the same antenna and orients the position of point 12, which is a reference point for the system but has no structural existence. The antenna includes half-portions 10 and 11 which are generally triangular in shape and have respective vertexes adjacent to point 12. Each half-portion 10 or 11 encompasses an angle $\alpha$ which is bisected by a center line 13 or 14, respectively, passing down their center. However, it is to be noted that neither half-portion 10 nor 11 is symmetrical about its center line.

Each half-portion 10 or 11 has transverse teeth extending on opposite sides of an inner triangular-shaped segment that is defined by an angle $\beta$. Angle $\beta$ is symmetrically placed within angle $\alpha$.

The two planes of half-portions 10 and 11 are oriented apart by an angle $\phi$, which can vary from 180° to 0°. Increasing angle $\phi$ beyond 180° causes it to repeat.

A plurality of teeth 10a, 10b through 10L are formed on half-portion 10; and a similar plurality of teeth 11a, 11b through 11L are formed on half-portion 11. In FIGURE 1, each of the teeth is trapezoidal in form when its transverse parallel sides are extended to meet center-line 13 or 14; and the parallel sides are perpendicular to their center-line. The teeth vary in size and spacing in a logarithmically periodic manner from terminal point 12. Thus, each tooth has parallel sides 21 and 22 with outer side 22 being the more distant of the two from point 12. Each tooth is bounded on its remaining two sides by lines defining angles $\alpha$ and $\beta$.

The location and size of the set of teeth of half-portion 10 on the left side of its center line 13 will first be defined. The location and size of the remaining teeth of the antenna can then be defined in terms of this set of teeth. The distances along center line 13 between point 12 and the outer sides 22 of alternate teeth 10a, 10c through 10L

are represented by distances $R_1$, $R_2$ through $R_L$. Any two consecutive values of R are $R_N$ and $R_{N+1}$, with the latter being the smaller distance. Similarly, $r_1$, $r_2$ through $r_L$ represent distances of the inner sides of the same teeth from point 12; and of any consecutive pair of $r$ are $r_N$ and $r_{N+1}$, with the latter being the smaller distance. They are defined by the following expression:

$$\tau=\frac{R_{N+1}}{R_N}=\frac{r_{N+1}}{r_N} \quad (1)$$

where $\tau$ is a constant less than one, which is fixed for a given antenna design.

Expression 1 positions the teeth with respect to each other along the center-line but does not specify the width of the teeth. The width of any tooth of the set is the difference between $R_n$ and $r_n$, which are related by the following expression:

$$\sigma=\frac{r_N}{R_N} \quad (2)$$

where $\sigma$ is constant for a given antenna design.

Consequently, expression 2 completes the general definition of the set of teeth on the left side of center-line 13 in FIGURE 1.

The remaining teeth of antenna half-portion 10 can then be defined, because the teeth on the right-hand side of center-line 13 have their sides 22 and 21 aligned with the defined sides 21 and 22 respectively of the left-hand side, with the teeth on the right-hand side aligning with spaces between teeth on the left-hand side.

Furthermore, the teeth on the opposite antenna half-portion 11 are also thereby defined, because half-portions 10 and 11 are identically shaped. Thus, in FIGURE 1 the teeth on the right-hand side of portion 11 correspond to the teeth on the left-hand side of portion 10. Likewise, the teeth on the left-hand side of portion 11 correspond to the teeth on the right-hand side of portion 10.

Although the half-portions 10 and 11 are constructed in the same manner, they are positioned unsymmetrically with respect to each other in the sense that one is not the image of the other. This prevents the same antenna response from being obtained by positioning a single half-portion over a ground-plane that bisects angle $\psi$.

Expressions 1 and 2 determine a geometric-ratio sequence for tooth sizing and for tooth spacing. However, they permit different geometric-sequencies having the same geometric-ratio to define distances to inner and outer sides of a tooth, respectively. A particularly useful special case occurs when the teeth are similarly proportioned on opposite sides; and this is obtained when

$$\sigma=\sqrt{\tau} \quad (3)$$

When angle $\psi$ is less than 180°, an asymmetrical radiation pattern 26 shown in FIGURE 2 is obtained, with the major lobe pointing in the direction of arrow 27. The primary polarization of the radiation is parallel to teeth sides 21 and 22. A secondary transverse polarization is also obtained, which is small and can be controlled. The radiation pattern is discussed below in more detail.

Theoretically, an infinite bandwidth from zero to infinite cycles-per-second can be obtained for the antenna by making each half-portion infinitely long, wherein the teeth become infinitely small as vertex 12 is approached and infinitely large in the opposite direction. In practice, finite dimensions are mandatory, and a finite number of teeth must be used. Thus, the bandwidth is then no longer infinite, but nevertheless, extremely large bandwidths can still be obtained. The number of teeth used in the given antenna is therefore somewhat arbitrary, although generally speaking more than two teeth must be used to obtain a structure which is logarithmically periodic. In each case, there is a practical limit to the size of the largest tooth, and the smallest tooth also has its limit. Thus, in antenna half-portion 10 in FIGURE 1, tooth 10L is the smallest, and tooth 10a is the largest. Accordingly, the small triangular part 23 of half-portion 10 near vertex 12 has no teeth, due to the practical difficulties in making very small teeth. However, the outer side 24 of triangular portion 23 performs like the outer side 22 of a tooth, and it acts electrically like the smallest tooth of the antenna.



Half-portion 11 similarly has a small triangular portion 25 with an outer side 30 that corresponds to triangular part 23 and its outer side 24, respectively.

Structurally, the size of the largest and smallest teeth determine the lowest and highest frequency limits, respectively, of the range.

The high-frequency limit of the frequency independent range is reached when the length of smallest side 24 or 25 from the center-line to its $\alpha$-boundary becomes about one-tenth of a wavelength of the radiated frequency.

On the other hand, the low frequency limit of the range is determined when the length of the largest side 22a, measured from center-line 13 to its $\alpha$-boundary, is approximately one-quarter wavelength.

Although the frequency limits are determined by the sizes of the largest and smallest teeth in the structure, it is by no means to be implied that radiation occurs only from these teeth at the respective frequency limits. Rather, radiation at all times occurs from several of the teeth in varying degrees in a complex manner.

Ideally, the sheets of metal from which each of the antenna half-portions 10 and 11 is made have tapered thickness as explained above. In practice, however, it has been found that stepped thickness can be used to the same effect, and further that uniform thickness can be used without substantially inhibiting the operation of the antenna for very large bandwidths of the order of five-to-one.

The antenna of FIGURE 1 can be fed by means of either a balanced or an unbalanced line, but special precautions must be taken to prevent the line from interfering with the radiation pattern. An unbalanced line, coaxial cable 29, is used in FIGURES 1 and 2. In order to prevent it from interfering with the radiation pattern, it is brought along the solid triangular portion within angle $\beta$, with the outer conductor making contact therewith, and it terminates at the apex of half-portion 11. Its inner conductor 28 extends from the end of coaxial line 29 across the space between the apexes of the half-portions, and connects to the apex of half-portion 10. Outer conductor 29 is not at ground potential along half-portion 11 but varies in a manner that automatically transduces the unbalanced-line impedance to a balanced impedance connection for the antenna without unbalancing the antenna pattern. The near-zone electro-magnetic fields associated with the antenna decrease rapidly as extremity 22a is approached. Therefore, the presence of coaxial line 29 has little effect on the field and hence on the balance of the antenna structure. This effectively produces a very-wide-band balanced feed for the antenna.

Also, a balanced line can be connected to the antenna by being brought toward the antenna in FIGURE 2 along the direction of arrow 27, with opposite sides of the line being connected to the apexes of the respective half-portions. If the transmission line is brought from the side of the antenna that is perpendicular to the paper at point 27 in FIGURE 2, it interferes with the radiation pattern to some degree, which in many cases makes such type of connection undesirable.

Although each half-portion 10 and 11 is in a respective plane in FIGURES 1 and 2, each can also be folded about its center-line 13 and 14. FIGURE 16 shows an end view of such antenna where $\Psi$ is 180° and $x$ is the fold angle between the radical members of half-portion 10 having respective end teeth 22a and 22b. The figure-eight type radiation pattern 15 of this antenna is made more omnidirectional as angle $x$ is made smaller. Optimum omnidirectionality is obtained with $x$ between 120° and 130°. As angle $x$ is made smaller the antenna be-

comes more frequency-sensitive and its bandwidth decreases.

We have also discovered structural modifications of the antenna given in FIGURES 1 and 2, which greatly facilitate the use of the invention. FIGURES 3 through 7 illustrate such modifications, and teach how the invention can be constructed from conducting rods or wire, while still maintaining the required operating characteristics of the invention. With regard to FIGURE 3, rods are used to provide an outline of the configuration given in FIGURE 1. Although the antenna of FIGURE 1 does not have an identical complementary structure, it still provides a clear distinction between the teeth and spaces between the teeth. The structure of FIGURE 3 is hence even farther from the complementary principle, since the internal portion of any tooth defined by rods or wire is also a space. Nevertheless, we have experimentally determined that the structure of FIGURE 3 operates in substantially the same manner as the structure of FIGURE 1.

FIGURE 3 also includes two half-portions 10 and 11. Half-portion 10 includes a plurality of transverse rods 32a, 32b through 32L. Similarly, half-portion 11 comprises transverse rods 33a, 33b through 33L. The rods of half-portion 10 are positioned with respect to the center of the antenna in the same manner as tooth sides 21 and 22 were located in FIGURE 1, that is, by means of expressions 1 and 2 above. Rod sections 36a, 36b through 36L are placed on the boundary of the teeth of portion 10, as defined by angle $\alpha$. Similarly, the teeth in portion 11 have lateral bounds provided by rod sections 37a, 37b through 37L, which likewise are aligned along angle $\alpha$. A pair of rods 41 and 42 are fixed to portion 10 along the sides of angle $\beta$; and rods 43 and 44 are similarly positioned in portion 11. A centrally positioned rod 46 is also provided along half-portion 10, while coaxial cable 29 is brought centrally along half-portion 11 with its outer conductor connected to respective transverse rods 33. Its inner conductor 28 exits from the coaxial line at the apex of portion 11 and connects to the apex of portion 10.

The antenna system of FIGURE 4 is similar to that shown in FIGURE 3 and like portions carry like reference numbers. However, in effect, angle $\beta$ is made zero in FIGURE 4 by not providing rods 41, 42, 43 and 44.

FIGURE 5 shows a modification of the antenna of FIGURE 4, wherein the trapezoidal teeth elements of FIGURE 4 are modified into triangular shapes. Thus, in FIGURE 5 the two antenna portions 10 and 11 are again confined within an angle $\alpha$; and like FIGURE 4, there is also provided a center rod 46 in portion 10 of FIGURE 5 and coaxial cable 29 along portion 11. In effect, items 46 and 29 are bisectors of angle $\alpha$.

Thus, in FIGURE 5, portion 10 is composed of transverse rods 51a, 51b through 51L. Similarly, portion 11 comprises transverse rods 53a, 53b through 53L. The rods connected at their ends to form transverse triangular teeth. The outer apex of each triangular tooth lies on a defining line of angle $\alpha$.

If the antenna of FIGURE 5 were superimposedl on a corresponding antenna of the type in FIGURE 1, the apexes of the triangular teeth of FIGURE 5 would be located on the lateral sides of corresponding trapezoidal teeth.

The positioning of the transverse rods in FIGURE 5 is preferably determined by means of expressions 1 and 2 given above. However, the terms of the expressions are preferably defined in FIGURE 5 with respect to the apex points of the transverse teeth. This is done with respect to antenna half-portion 10 by designating its apexes on the right-hand side in FIGURE 5 by means of R and by designating its apexes on the left-hand side by $r$. The dimensions R and $r$ are measured from a transverse line 60 that passes through terminal point 12 and is transverse to center-line members 46 and 29. The end



of each rod 51a and 53a farthest from point 12 is considered an apex, and each has a distance $R_1$ from line 60.

With this definition of the positions of the elements in FIGURE 5, it will be found that their points of intersection with center-line members 46 and 29 also satisfy expressions 1 and 2 above, with expression 3 being a specific case. Also, it will be noted that alternate elements in FIGURE 5 are parallel to each other; for example, elements 51a and 51c are parallel, 51b and 51d are parallel, and so forth.

In FIGURE 5, the apex part of portion 10 is defined by rods 56, 57 and 51L. Likewise, in portion 11 the apex triangle is defined by rods 58, 59 and 53L.

FIGURE 2 may also represent a side view of any FIGURES 3, 4 and 5, wherein their two half-portions are separated by an angle $\Psi$ which may vary from 0° to 180°.

The basic triangular-toothed configuration of FIGURE 5 leads to the greatest structural simplification in some cases over other forms of the invention, while maintaining the desired operating conditions. Thus, the configuration of FIGURE 5, as also do FIGURES 3 and 4, permits wire structures for very large antennas capable of having extreme broadbandedness which extends into the lower frequencies. In order to lower the low frequency limit of the antenna range, it is necessary to increase the size of the larger elements of the antenna. Since the width of the largest transverse element approximates one-half wavelength of the lowest frequency, it can be realized that at very low frequencies the transverse elements can become rather large.

FIGURES 6(A) and (B) illustrate how the antenna configuration given in FIGURE 5 can be constructed of wire. It is constructed using three poles 61, 62 and 63 firmly supported uprightly from the ground. Again the antenna comprises the two half-portions 10 and 11. A plural waisted insulator 64 is provided at the top of a pole 61 and is situated at the apex of the antenna. The poles are preferably wood so as not to interfere with the radiation. A pair of hooks 66 and 67 are respectively fastened in horizontal alignment to poles 62 and 63 near their top. Similarly, a second pair of hooks 68 and 69 are fastened with horizontal alignment to the lower portions of poles 62 and 63. A taunt line 71 is connected between hook 67 and the upper-middle waist of insulator 64. Line 71 consists of metal wire segments mechanically coupled but electrically separated by insulators 72. Similarly, another line segment 73 is connected between the upper-middle waist of insulator 64 and hook 66. Line 73 is likewise comprised of wire segments similarly coupled by insulators 72. Lines 71 and 73 are structural only and are interrupted electrically by the insulator to prevent them from having an antenna function. A dielectric type of structural line could preferably be used for lines 71 and 72 without insulators; however, no dielectric material is known which is properly stable under tension. The insulators 72 along lines 71 and 73 are positioned to support the apexes of the triangular teeth.

Transverse wires 51a through 51L are positioned between the supporting lines 71 and 73 with an angle $\alpha$ in the manner defined for FIGURE 5. Insulators 72 connect to the apex of each transverse tooth along lines defining $\alpha$.

In a like manner, the lower half-portion 11 of the antenna is strung between a pair of structural lines 81 and 82, which correspond respectively to lines 71 and 73. Thus, lines 81 and 82 are strung between the lower-middle waist of insulator 64 and hooks 68 and 69, respectively. A central wire 46 connects the elements of section 10 along the bisector of angle $\alpha$. Similarly, a central wire 47 connects the transverse elements of antenna portion 11 to bisect its angle $\alpha$. Central lines 46 and 47 connect to the upper and lower waists of insulator 64.

A balanced transmission line 83 is brought along pole 61. It fans away from the antenna and then is brought directly toward its apex, where the opposite sides of the

line respectively connect to the ends of leads 46 and 47. The directivity of the antenna system of FIGURES 6(A) and (B) is the direction of arrow 27 in FIGURE 6(A) and provides pattern 26 in that figure.

Where it is desired to make the antenna of FIGURE 6 have a symmetrical figure-eight pattern, angle $\psi$ should be 180°, and the entire antenna may be supported between two parallel upright poles in a manner which is obvious in view of the description of the antenna in FIGURE 6. A coaxial feed line is then preferably used, as given in the prior figures.

FIGURE 7 illustrates a rotatable single-mast mounting of the form of the invention shown in FIGURE 4, and like reference numbers are used for like components. The antenna system of FIGURE 7, for example, can be a radio-ham antenna which is preferably extremely broadband to receive many of the ham bands. Unlike other ham antennas, the one in FIGURE 7 does not require any tuning for the various bands, and furthermore it maintains a directivity which is constant for all bands within its range. Thus, if the antenna is designed for a fifteen-to-one range, it can provide a horizontally polarized transmission at various points in the spectrum between two and thirty megacycles. In FIGURE 7, the opposite halves of the antenna, 10 and 11, are supported on rotatable mast 86. The central members 46 and 47 of antenna portions 10 and 11 are step-tapered in cross-section, in order to enhance broadbandedness. The taper is largest at elements 32*a* and 33*a* and narrows to a point adjacent to the antenna apex. Also, in order to enhance broadbandedness the largest diameter rods are 32*a* and 33*a*, with the diameters of the rods decreasing as their positions approach the antenna apex.

Mast 86 can be made of conducting material, and when it is made of conducting material it should be connected to supports 46 and 47 at points midway between any two adjacent rods 32 or 33, respectively. It has been found experimentally that a metal mast does not interfere with the radiation pattern when it is connected to such midpoints, because it appears that voltage-null points exist along rods 46 and 47 at the points midway between adjacent transverse rods.

A coaxial transmission line 87 passes upwardly through mast 86, which is hollow, and passes outwardly through a hole 88 in the mast and has its outer conductor connected along central member 47 until it terminates at the apex of the antenna as taught with FIGURE 4. Thus, its center conductor 28 extends outwardly and connects to the end of central member 46. A dielectric block 89 connects the apex ends of half-portions 10 and 11 to provide mechanical rigidity only.

It has been found that the center-line conducting member 46 and 29 in FIGURES 4 and 5, and 46 and 47 in FIGURE 6 can be removed with some deterioration of broadbandedness but with substantial broadbandedness remaining. Then, balanced transmission lines are preferable, although a coaxial cable connected along the periphery of the teeth of one side to the apex could also be used to feed the antenna.

FIGURE 8 illustrates an omnidirectional form of the invention. With an oversimplification of statement which will be realized shortly, FIGURE 8 comprises two antennas of the type shown in FIGURE 1 positioned in space quadrature. The oversimplification referred to is that such two antennas do not have corresponding teeth. That is, the quadrature plane antennas have their teeth differently placed. A picturesque manner of describing the positioning of the teeth of each antenna half-portion 110 and 111 in FIGURE 8 is to say that the teeth of each provide a spiral staircase leading to the antenna terminal 112. The spiral effect is shown in FIGURE 9, which shows a logarithmic or equiangular spiral developed on a cone. Thus, one would have an antenna of the type in FIGURE 8 by passing two transverse planes 118 and 119 along the axis of the cones in FIGURE 9.

While theoretically the spiralling can extend to infinity, in practice, it must be finitely terminated. Thus in FIGURES 8 and 9, termination is defined by planes transversely intersecting the center-line of the half-portions 110 and 111 at points equally distant from terminal point 112.

FIGURE 10(A) shows an end view of the antenna of FIGURE 8, which provides an omnidirectional-type radiation pattern 91.

Half-portion 110 includes four radial members 131, 122, 123 and 124 shown in FIGURE 10(A), which are fastened together along the center-line of 113—114 that passes through both half-portions. In the same sense, there are two radial members on the opposite sides of center line 13 in FIGURE 1 to define half-portion 10. The same situation is found in each half-portion in each of FIGURES 1–9. A radial member thus is confined within an angle

$$\frac{\alpha}{2}$$

from the center line of a half-portion. Similarly, half-portion 111 includes four radial members 131, 132, 133 and 134. Each radial member is included within an angle

$$\frac{\alpha}{2}$$

from the antenna center line, as shown in FIGURE 8. In obtaining the spiral-staircase effect, the outer edge of any two adjacent spiral-related teeth, not being cut off by the bounding planes, such as 110*c* and 110*d*, have their respective outer sides defined by the expression:

$$\psi^{1/n}=\frac{R_{N+1}}{R_N}=\frac{r_{N+1}}{r_N} \tag{4}$$

Hence, distances $R_N$ and $R_{N+1}$ in expression 4 from a transverse plane passing through a point 112 are given by $R_3$ and $R_4$ for teeth 110*c* and 110*d*. Similarly, $r_N$ and $r_{N+1}$ are taken from the inner sides of consecutive spiral teeth to satisfy expression 4. Also, the center-line distance $r_N$ and $R_N$ of the inner and outer sides of any tooth from point 112 will also have the fixed ratio given in expression 2 above, and the special case of expression 3 can like wise be satisfied.

Antenna portion 111 is formed in the same manner as portion 110 except that the spiralling goes in reversed directions for the respective half-portions 110 and 111 looking from terminal point 112. Nevertheless, portion 111 is twisted 180° with respect to portion 110 about their center-line. Thus, tooth 110*b* corresponds to 111*b*, tooth 110*c* corresponds to tooth 111*c*, etc., with corresponding teeth being on opposite sides of the common center-line.

Due to the 180° reversal about the center-line of antenna half-portions 110 and 111 with respect to each other, the two half-portions are not antenna images of one another. Accordingly, one half-portion cannot be provided over a transverse ground-plane through point 112 to obtain the same omnidirectional-type response which is obtained with the two half-portions disposed as shown.

Although there are four radial members used in each half-portion of FIGURE 8, actually any number greater than two can be used, and the same rules apply for proportioning adjacent teeth in the spiral-staircase manner. The dimensions of an antenna having $m$ number of radial members per half-portion can be found as follows:

$$\psi^{\frac{1}{m}}=\frac{R_{N+1}}{R_N}=\frac{r_{N+1}}{r_N} \tag{5}$$

Where three radial members are used in each half-portion, an end view is shown in FIGURE 10(B). Extending the rationale to five radial members per half-portion, an end view is given by FIGURE 10(C). This can be extended to any number $m$ of radial members with the ultimate

limit being the spiral-grooved cones of FIGURE 9 as the number $m$ approaches infinity.

The omnidirectional-type patterns such as patterns 91, 92 and 93 in FIGURES 10(A), (B) and (C) are slightly distorted according to the number of radial members used per antenna portion. However, this deviation from a perfect omnidirectionality is generally small and not objectionable in practice, while at times has definite advantages.

FIGURE 11 is basically the same as FIGURE 8 except that it is made of wire network which simplifies construction in many cases. Thus, the individual radial sections of FIGURE 11 are outlined by wire to form the toothed-configuration of FIGURE 8. The transverse rods in FIGURE 11 do not intersect the coaxial cable 114, but merely fasten to its outer conductor. In practice, the rods are continuous and coaxial line 114 and center-rod 113 lie in a corner of their cross-over planes. The center-conductor 128 connects to the apex end of rod 113, which can be a solid conducting rod.

The antenna network of FIGURE 12 is a triangular-toothed version of the form in FIGURE 11 and has similarities to FIGURE 5. Accordingly, the variation from 11 and 12 is similar to the variations from FIGURES 4 to 5.

In regard to the three-dimensional structures given in FIGURES 8 through 12, it was stated above that opposite half-portions are not images. However, when the entire antenna assembly having both halves is erected over a ground plane, the image of the entire antenna is view in the ground plane and this does not interfere with the radiation pattern.

FIGURE 14(A) illustrates a rounded-tooth version of the form of the invention given in FIGURE 8. FIGURE 14(A) differs from FIGURE 8 in that in FIGURE 14(A) the edge of each tooth is a segment of a circle about terminal point 112. Thus, dimensions $R_M$ and $r_M$ in FIGURE 14(A) are taken from point 112 of the antenna to any point along a respective tooth edge. An improvement in the omnidirectionality of the radiation pattern was found in the rounded-toothed version of FIGURE 14(A) over the previously straight-toothed version of FIGURES 8, 11 and 12. Thus, the circular radiation pattern 94 shown in FIGURE 14(B) is obtained about an end view of the antenna given in FIGURE 13(A).

FIGURE 13 illustrates a modified version of FIGURE 1. Unlike FIGURE 1, where all the teeth have their inner and outer edges perpendicular to center-lines 13 and 14, the teeth in FIGURE 14 have their outer and inner sides 22 and 21 intersect center-lines 14 and 13 at an angle $\delta$. The points of intersection of the tooth edges with the center line are determined in the same manner as was given for FIGURE 1. That is, the points of intersection are determined by expressions 1 and 2 above. Otherwise the antenna in FIGURE 14 is the same as that shown in FIGURE 1, and a corresponding radiation pattern is obtained. The angle $\delta$ may be proportioned as desired, but better performance is taken if the teeth drop toward terminal point 12.

FIGURE 15 illustrates the forward radiation lobe of the antenna. There will also be a backward lobe, not shown here. The backward lobe is equal to the forward lobe only when angle $\psi$ is 180°. As $\psi$ decreases, the backward lobe decreases, and accordingly the front-to-back intensity ratio increases. Thus, by making $\psi$ small, the back lobe is made minor in comparison to the forward lobe, and can be made to have an intensity of twenty or thirty decibels below that of the forward lobe.

Antenna 150 in FIGURE 15 is illustrated with respect to $x$, $y$ and $z$ coordinate axes. These axes intersect at the apex terminal point 12 of antenna 150. Thus, axis $z$ aligns centrally with the entire antenna structure to bisect angle $\psi$. Axis $y$ is parallel to the transverse rods of the antenna, which is of the type shown in FIGURE 4. The radiation E-vector is parallel to the $y$ axis. Accordingly the $xy$ plane will be called the E-plane. Furthermore, the radiation H-vector is parallel to the $z$ axis, and the $xz$ plane is called the H-plane.

When angle $\psi$ is decreased from 180° toward zero with all other parameters remaining constant, the beam-width 151 of the E-plane pattern remains substantially fixed. However, the beam-width 152 of the H-plane pattern increases in beam-width. Furthermore, the front-to-back ratio increases. The H-plane variation is a first order effect with variataion of $\psi$.

When angle $\alpha$ is decreased with all other parameters remaining constant including angle $\psi$, there is a small second-order decrease in E-plane beam-width 151. However, there is a first-order decrease in H-plane beam-width 152. Nevertheless, there is a practical limit to decreasing angle $\alpha$ without increasing $\tau$. The limit can be specified approximately by referring to a parameter $\epsilon$ which relates tooth width S to tooth length L, shown in FIGURE 15, according to the following expression:

$$\epsilon=\frac{S}{L} \qquad (6)$$

It has been found desirable to maintain $\epsilon$ equal to or less than 0.6.

If the tooth-spacing ratio $\tau$ of expression 1 above is increased while all other parameters remain fixed, the number of teeth, of course, increases for a given sized antenna. As a consequence, both beam-widths 151 and 152 in the E and H-planes, respectively, decrease in a small corresponding amount, which is a second-order effect.

Although this invention has been described with respect to particular embodiments thereof, it is not to be so limited as changes and modifications may be made therein which are within the full intended scope of the invention as defined by the appended claims.

We claim:

1. A straight-toothed logarithmically periodic antenna comprising two half-portions, each comprising two opposite radial members connected along the central part of their half-portion, the two half-portions bounding a solid angle $\psi$ and being generally triangular in shape and having adjacent apexes, each of said radial members being bounded by an apex angle

$$\frac{\alpha}{2}$$

from a line along the central part of either half-portion, first and second center-conducting members respectively extending from the apexes to the ends of the respective half-portions along their central parts, each half-portion having a plurality of rods cross-connected to its center-conducting member and terminated by the bounds of its angle

$$\frac{\alpha}{2}$$

connecting means provided at the ends of said transverse rods along the outer boundaries of each angle

$$\frac{\alpha}{2}$$

of each radial member, respective teeth closed by said connecting means, the connecting means on opposite radial members of each half-portion being staggered with respect to each other, the distances along a radial from the apex of said transverse rods of each radial member being a geometric sequence, and a transmission line having opposite sides connected to the respective apexes of said two half-portions.

2. An antenna as defined in claim 1 in which the diameters of said rods are proportioned to their distance from their apex.

3. An antenna as defined in claim 1 in which alternate rods of each half-portion are parallel.

4. An antenna as defined in claim 1 in which both

antenna half-portions and their radial members lie in the same plane.

5. An antenna as defined in claim 1 in which a plurality of rod portions comprise said connecting means, with said rod portions of each radial member being aligned.

6. A triangular-toothed logarithmically periodic antenna comprising opposite antenna half-portions, each half-portion being in a respective plane and having a generally-triangular shape, said half-portions having adjacent apexes and being bounded by a respective apex plane-angle $\alpha$, the respective planes being oriented by a solid-angle $\phi$, a respective conducting center-member provided with each half-portion and positioned along the bisector of its angle $\alpha$, a plurality of rods connected across said center-member of each half-portion, adjacent rods connected at their ends along the boundaries of angle $\alpha$ and there terminated, alternate rods being parallel, the distances from the apex of each half-portion to the opposite ends of each of its rods having a geometric-sequence ratio $\sigma$.

7. A three-dimensional straight-toothed logarithmically periodic antenna comprising two opposite half-portions which are aligned along the same center-line, each half-portion triangularly tapering to an apex, with the apexes of both half-portions being closely adjacent, a transmission-line having opposite sides connected to the respective apexes, each half-portion having more than two radial-toothed members symmetrically connected along said center-line, the teeth of each member extending outwardly from the center-line of its half-portion, each radial member having an apex angle

$$\frac{\alpha}{2}$$

with respect to its center-line, the teeth of said radial members of each half-section aligned along a conical logarithmic spiral beginning at the respective apex of each half section.

8. A three-dimensional periodic antenna as defined in claim 7 in which the thickness of the radial sections increases linearly from the apex of each antenna half-portion.

9. A three-dimensional periodic antenna as defined in claim 7 in which said teeth are formed of rods located along the periphery of said teeth, a respective center rod positioned along the center-line of each of said half-portions and connected to transverse ones of the rods forming said teeth.

10. A three-dimensional logarithmically periodic antenna comprising a pair of half-portions aligned along a common center-line, each half-portion formed in the same manner as the other but one rotated 180° about the center-line with respect to the other, each half-portion having an apex, with the apexes being closely adjacent, a respective center member of each half-portion passing along its center-line, more than two radial members provided in each half-portion and being symmetrically disposed around their center-line, each radial member having a triangular shape and a common apex, each radial member bounded by an apex angle of

$$\frac{\alpha}{2}$$

measured from the center-line, a transmission-line having opposite sides connected respectively to the apexes of said antenna half-portions, each radial member comprising a plurality of triangular teeth positioned transversely from



said center-line, each of said teeth having its outer side bounded by angle

$$\frac{\alpha}{2}$$

the teeth of the radial members of any one half-portion arranged along a conical logarithmic spiral from the apex of the half-portion.

11. A triangular-toothed three-dimensional antenna as defined in claim 10 in which each of said antenna half-portions is formed from wire aligned with the periphery of said teeth, a central wire being provided along the center-line of each of said half-portions and connecting to the wires forming its teeth that cross said center-line.

12. An antenna as defined in claim 11 in which four radial members are provided for each antenna half-portion.

13. A three-dimensional rounded-toothed logarithmically periodic antenna comprising two half-portions symmetrically aligned about a center-line passing through said antenna, with each half-portion having an apex, and said apexes being closely adjacent although separated from one another, a transmission line having opposite sides connected to the respective apexes, a plurality of more than two radial members comprising each half-section, each radial member being generally triangular in shape and having an apex at the apex of its antenna half-portion, with each radial member having an apex angle of

$$\frac{\alpha}{2}$$

a plurality of teeth formed in each radial member, with each tooth having inner and outer sides which are circular about its apex as a center, the teeth of each half-portion arranged to form a conical logarithmic spiral from its apex, the distances of adjacent sides of adjacent spiral teeth having a fixed ratio $\sigma$, the opposite antenna half-portions being formed in the same manner but being rotated 180° with respect to each other about the center-line.

14. A curved-tooth three-dimensional antenna as defined in claim 13 in which each half-portion includes four symmetrically placed radial members.


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Exhibit A

July 5, 1966 I. S. BLONDER ETAL 3,259,904

ANTENNA HAVING COMBINED SUPPORT AND LEAD-IN

Filed Nov. 21, 1963

FILED
AUG 27 1968
AT O'CLOCK
FILBERT A. WAGNER, JR.
CLERK

EXHIBIT NO. 26
TIMOTHY L. SHACKELFORD
OFFICIAL COURT REPORTER

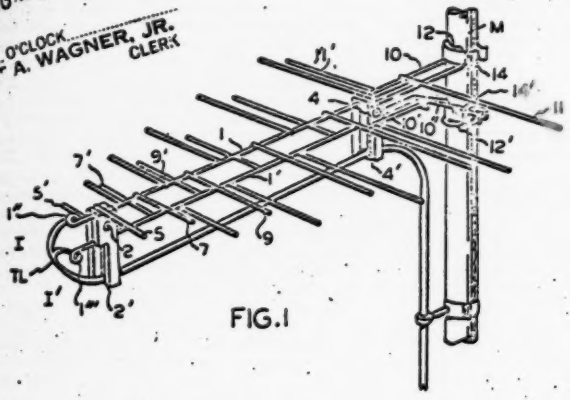


FIG. 1

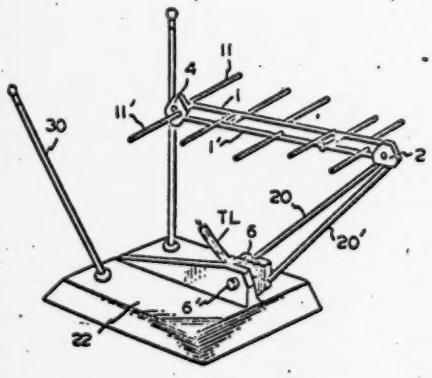


FIG. 2

INVENTORS
ISAAC S. BLONDER
ABRAHAM SCHENFELD

BY Rines and Rines
ATTORNEYS

United States Patent Office

3,259,904
Patented July 5, 1966

1

3,259,904

# ANTENNA HAVING COMBINED SUPPORT AND LEAD-IN

Isaac S. Blonder, West Orange, N.J., and Abraham Schenfeld, New York, N.Y., assignors to Blonder-Tongue Electronics, Newark, N.J., a corporation of New Jersey

Filed Nov. 21, 1963, Ser. No. 325,511
6 Claims. (Cl. 343—792.5)

The present invention relates to directive antennas and, more specifically, to antennas adapted for receiving very high frequencies, such as the ultra-high-frequency television band.

Numerous types of antennas have been evolved for broad-band directive radio and television reception including driven arrays, Yagi-type arrays, log periodic linear and V-type antennas, helical antennas and other configurations. The problems of mounting such antennas upon masts for outdoor operation or upon portable structures adapted for directional adjustment in connection with indoor reception have, however, long plagued the art; the mounting and adjusting structures introducing "ghosts" and other deleterious electrical field-pattern aberrations over the band. It is to the improvement of such mounting structures and the minimizing of electrical interfering effects over a wide band of frequencies, including stabilizing of outdoor performance and providing for ready adjustability in indoor performance, that the present invention is primarily directed.

A further object of the invention is to provide a new and improved antenna particularly adapted for ultra-high-frequency television reception.

Still another object is to provide a novel antenna of improved performance for more general use, also.

Other objects will be made more evident hereinafter and will be particularly pointed out in the appended claims. In summary, however, the invention contemplates a pair of rigid conductors held spaced a predetermined vertical distance apart in a vertical plane, first and second pluralities of horizontal dipole elements lying in corresponding first and second vertically spaced horizontal planes containing the respective conductors, the dipole elements extending from opposite sides of each conductor at successive points therealong with dipole elements connected to one conductor extending in opposite horizontal directions to the corresponding dipole elements of the other conductor, the length of the dipole elements successively increasing from one end of the conductors towards the other end thereof, means for feeding the energy received by the antenna at the said one end of the conductors, and means for mounting the antenna comprising a further pair of rigid, preferably diverging, conductive extensions of the said conductors mechanically secured in rigid spaced-apart relation at the end thereof. Further preferred details are hereinafter set forth.

The invention will now be described in connection with the accompanying drawing, FIG. 1 of which is an isometric view of an outdoor preferred embodiment thereof; and

FIG. 2 is a similar view of a modified indoor version.

Referring to FIG. 1, the antenna comprises a pair of rigid conductors 1, 1' held spaced apart a predetermined vertical distance in a vertical plane by forward and rearward insulating clamps 2 and 4. While the terms "vertical" and "horizontal" as herein employed describe the preferred orientation for ultra-high-frequency television reception, they are intended more generically to be illustrative of relative orientations without being confined to actual direction. Similarly, though the invention is described in connection with radio-wave reception, the antenna may also be used for transmission, if desired, as is well known.

2

Unlike prior-art arrays, including Yagi arrays, conventional log-periodic structure and the like, first and second pluralities of horizontal dipole elements 5, 7, 9 . . . 11 and 5', 7', 9' . . . 11' are provided, lying in corresponding first and second vertically spaced horizontal planes 1 and 1' containing the respective longitudinal conductors 1 and 1'. The dipole elements are shown angularly extending transversely from opposite sides of each conductor at successive points therealong. The dipole elements connected to one conductor, moreover, extend in opposite horizontal directions to the corresponding dipole elements of the other conductor (such as 5 to the right 5' to the left; 7 to the right, 7' to the left; and so on). The length of the dipole elements preferably successively increases from one end (5, 5' being shortest) towards the other end (11, 11' being longest), as is well known, to provide directivity. A parallel-wire transmission line TL is connected at looped terminal portions 1'' and 1''' beyond the clamp 2 that secures the connecting portions 1'' and 1''' in spaced-apart relation, extending outside or to the left of the smallest dipole elements 5, 5'. The line TL may be supported below the antenna by depending guides 2' and 4' in the respective clamps 2 and 4, the latter being shown positioned near the largest dipole elements 11, 11'.

The antenna of FIG. 1 is mounted upon a mast M through the use of pairs of horizontally spaced conductor-loop extensions 10 and 10', shown extending to the right beyond the longest dipole elements 11, 11'. The extensions 10, 10', respectively, terminate in upwardly and downwardly extending vertical loops 12 and 12' that may be transversely curved to fit the mast M, as shown, and are securely mechanically strapped at 14 and 14' to the mast to hold the system 1–1' in rigid spaced-apart relation at the mast end. Further to aid in mechanical stability, the extension 10', while in part initially extending in the lower horizontal plane 1', diverges downwardly at 16''. Fortuitously, this mechanical stability-providing diverging construction has been found minimally to affect the electrical field pattern, particularly if the length of the extension between the longest elements 11, 11' and the mast M is made comparable to the separation along conductor 1 and 1' of the last dipole elements 11 from the next-to-the-last element, to its left in FIG. 1. Minimal field aberrations and "ghost" reflections over the complete ultra-high-frequency band, for example, has been thus attained with the above construction, together with satisfactory broad-band impedance matching, provided further that the vertical separation distance of the rigid conductors 1, 1' is kept less than the average distance between successive dipole elements (preferably the order of an inch for UHF band operation), and which, in turn, is kept much less than the wavelengths involved, as is well known. At the UHF channel 47 frequency, for example (671 megacycles), a 20 decibel front-to-back ratio has been obtained with this construction, providing about a 36-degree half-power horizontal beam width and no detectable forward secondary lobes.

This same general type of construction has also been found admirably suited for indoor direction adjustable antennas, as shown in FIG. 2. In this embodiment, however, the small-dipole end of the antenna is used not only for the connection to the transmission line, but also for the support-providing extensions. These extensions are illustrated as rigid conductors 20 and 20' depending at preferably an acute angle below the antenna at the insulating clamp 2 and slightly diverging for mechanical and impedance-matching purposes, being clamped at their bottom or free ends by a further insulating clamp 6. The transmission line TL is thus connected to the conductors 1 and 1' by these combined extension-supporting and transmission-line feed members 20, 20'. The clamp 6 is pivoted at 6' to a bracket carried by a base 22 so that the

members 1-1', 20-20' may be adjusted as a unit for both electrical impedance-matching purposes and appropriate phasing action for reception-direction adjustment, the length of the preferably diverging extension lines 20, 20' being made substantially equal to the length of the rigid antenna-supporting conductors 1, 1'.

If VHF reception is also to be provided, it has been found that minimal interference is caused by the antenna of the present invention if V-type VHF dipoles 30 are mounted on the base forward of the pivoted clamp 6 and with a sufficient included angle in the V to contain the array of the invention.

Further modifications will occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. An antenna for ultra-high-frequency operation and the like, having, in combination, a pair of rigid conductors held spaced a predetermined vertical distance apart in a vertical plane, first and second pluralities of horizontal dipole elements lying in corresponding first and second vertically spaced horizontal planes containing the respective conductors, the dipole elements extending from opposite sides of each conductor at successive points therealong with dipole elements connected to one conductor extending in opposite horizontal directions to the corresponding dipole elements of the other conductor, the length of the dipole elements successively increasing from one end of the conductors towards the other end thereof, means for connecting a parallel-wire transmission line to the said one end of the conductors and means for mounting the antenna comprising a further pair of rigid diverging conductive extensions of said conductors mechanically secured in rigid spaced-apart relation at an end thereof, the said diverging conductive extensions being provided at the said other end of the pair of rigid conductors and each comprising a pair of horizontally spaced conductors terminally provided with a vertical loop, and the said mechanical securing means comprising mast-strapping means for strapping the said vertical loops, and the distance of the said mast-strapping loops from the said other end being comparable to the distance between the longest and next-to-longest pairs of dipole elements of the antenna.

2. An antenna for ultra-high-frequency operation and the like, having, in combination, a pair of rigid conductors held spaced a predetermined vertical distance apart in a vertical plane, first and second pluralities of horizontal dipole elements lying in corresponding first and second vertically spaced horizontal planes containing the respective conductors, the dipole elements extending from opposite sides of each conductor at successive points therealong with dipole elements connected to one conductor extending in opposite horizontal directions to the corresponding dipole elements of the other conductor, the length of the dipole elements successively increasing from one end of the conductors towards the other end thereof, means for connecting a parallel-wire transmission line to the said one end of the conductors and means for mounting the antenna comprising a further pair of rigid diverging conductive extensions of said conductors mechanically secured in rigid spaced-apart relation at an end thereof, the transmission-line connecting means and the diverging conductive extensions being combined and extending downward from the said one end to include an acute angle between the dipole carrying conductors and their extensions.

3. An antenna as claimed in claim 2 and in which the conductive extensions are clamped at their free ends against relative movement with the clamp being pivotally mounted upon a base to permit adjustment, as a unit, of the dipole-carrying conductors and their extensions.

4. An antenna as claimed in claim 3 and in which a pair of V-type dipole elements for different frequency reception, are mounted on the said base forward of the pivotal clamp, with the said horizontal dipole elements contained within the V.

5. An antenna for operation over a predetermined frequency band, having, in combination, a pair of rigid longitudinal conductors held spaced a predetermined vertical distance apart in a vertical plane, first and second pluralities of dipole elements lying in corresponding first and second vertically spaced horizontal planes containing the respective conductors, the dipole elements extending from opposite sides of and transversely at an angle to each conductor at successive points therealong with dipole elements connected to one conductor extending in opposite direction to the corresponding dipole elements of the other conductor, the length of the dipole elements successively increasing from one end of the conductors towards the other end thereof, means for connecting a parallel-wire transmission line to the said one end of the conductors, rigid insulating means securing the said connecting means mechanically in spaced-apart relation and connected with means for supporting the transmission line near the said one end, and means for mounting the antenna at a region of the said conductors remote from the said one end, further rigid insulating means being provided for securing the said longitudinal conductors mechanically in rigid spaced-apart relation near the said region, the said vertical distance being less than the distances between the said successive points and less than the wavelengths of the said band.

6. An antenna as claimed in claim 2 and in which the lengths of the said conductors and of their extensions are substantially equal.

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HERMAN KARL SAALBACH, *Primary Examiner.*

C. BARAFF, E. LIEBERMAN, *Assistant Examiners.*

Copy received Wash. [illegible]

7/27/64

Never officially mailed but handed to me by Finkelstein draft. S 7/27/64

UNITED STATES DISTRICT COURT
DELAWARE

Dear Sam:

Your letter of July 17, 1964, comes as a surprise. The uncordial sentiments and threats therein expressed would be consistent only with a claim for non-payment of royalties. We have worked with you and talked with you about this; but there seems to be no will on your part to understand our prob[lem].

Advertisements must frequently break fast, literature and mats must be revised and re-edited on very short notice.

We want your review and approval; but these must be realistic and made with a realistic view to the exigencies and deadlines of the always immediate situation.

Delay and extended consideration in review can amount to a review in which "...authorization...."is"...unreasonably withheld..."

Also, when the Foundation decided to commercialize some of its developments, the decision necessarily entailed at least a partial entry into the commercial world where advertising and the exploitation of ideas help to produce [income].

It has been our impression that the advertising mention of the source of a concept, idea or development has always been of material benefit to the source and the advertiser. Whether it was the University of Wisconsin Vitamin D or Armour Research everyone has gained. Even "By appointment to her Majesty..." is not unknown. And we are reminded of the many advertisements which give credit to Government agencies such as NASA or boast of the use of principles developed by other [agencies] and universities. In our system, there is nothing evil about advertising. Our one concern is that the advertising be absolutely true.

FILED

AUG 27 1969

AT ..... O'CLOCK .....
GILBERT A. WAGNER, JR.
CLERK

A00209

-2-

I have an idea which will answer both our problems:

Can we agree, in advance, on a series of legends which may be used on advertising of antennae made by us under the license--even to the extent of agreeing on the relative size and location of the legends.

We see nothing wrong with the legend:

"Brings the acknowledged Log-Periodic design of the Antenna Research Laboratories of the University of Illinois to a new peak of performance".

Every word in it is absolutely true. The only apparent "puffing" is the phrase "new peak" which we believe to be exactly correct. We are the licensee; we are spending our own money on commercial development; and we are paying substantial royalties.

The license agreement envisioned advertising. The basic operative provision is that "authorization will not be unreasonably withheld."

So far, we have heard nothing but complaints or refusals.

Since authorization is not to be unreasonably withheld and since our advertising must often be revised and break fast, we ask you to supply us with a series of "authorized" legends which we may thereafter use without further complaint from you on this score.

If, thereafter, we find it desirable to use a new legend, we will submit it to you together with the copy, if that is ready, for fast action,--asking again that you keep in mind that proper commercial operation and deadlines often require that reasonable action be rapid action.

Sincerely yours,

cc: Mr. James C. Colvin

RECEIVED
AUG 13 1964
MERRIAM, SMITH & MARSHALL

JFD

# JFD ELECTRONICS CORP.

August 12, 1964

University of Illinois Foundation
University of Illinois
Champaign, Illinois

Attention: Mr. James Colvin

Re: Copy Clearance for
LPV Antennas

Dear Jim:

A few weeks ago, when Sam Smith was in town, I met with him at Mr. Faber's office and amongst the things we discussed was the question of clearance of copy material used in our selling campaign on LPV antennas.

At that meeting I proposed to Sam a plan whereby we could save a lot of time and avoid problems in preparing our advertisements and catalog brochures and also avoid the risk of having you object to the phrases and copy content therein. I suggested that we submit to you a list of statements that we have used in all of our past literature referencing the University of Illinois and the University of Illinois Antenna Laboratories and have you review them and agree in advance on this series of legends that we may be free to include in any advertising or catalog work on LPV antennas made by us under the license.

Once we have these authorized legends, we will thereafter work our ads and literature around them so that we can expect a submitted proof to clear without any problem or delay. I believe that within the scope of the approved legends, we will be able to still retain enough of a variety so as not to make our literature or ads stereotyped or repetitive.



A00313

JFD

# JFD ELECTRONICS CORP.

Mr. James Colvin (Cont.)

We have four (4) areas in which we have prepared material:

1. World's Fair Literature
2. Catalog and Price List Literature
3. Commercials, Magazines, Trade Papers
4. JFD Product Literature

We would like you to review the phrases used in the first and second categories as follows:

1. World's Fair Literature

Developed by the University of Illinois Antenna Research Laboratories.

Produced by JFD Electronics Corporation under Exclusive Licence from the University of Illinois Foundation.

The JFD LPV is designed according to the patented Log-Periodic geometric formula of the famous Antenna Research Laboratories of the University of Illinois.

Only JFD is licensed exclusively by the University of Illinois Foundation to make the patented Log-Periodic LPV and all other Log-Periodic type TV and FM antennas.

No other so-called Log-Periodic antenna can work like the JFD LPV because only JFD uses the original patented Log Periodic formula of the Antenna Research Laboratories of the University of Illinois.



A00314

X617-Ltd

JFD

# JFD ELECTRONICS CORP.

Mr. James Colvin (Cont.)

2. Catalogs and Price List Literature

Formulated according to the patented geometrically derived logarithmic-periodic scale of the Antenna Research Laboratories of the University of Illinois.

X Developed at the University of Illinois Antenna Research Lab.

Developed by the University of Illinois Antenna Research Lab.

This new concept has been related to TV-FM antennas exclusively for JFD by Prof. Paul E. Mayes of the Antenna Research Laboratory, Universityof Illinois.

Our advertising department is reviewing the remaining literature and some time next week I will send you the information on the third category to be followed shortly thereafter by the last.

Would you please review the above phrases and indicate which we can continue to use in the preparation of our advertising material.

Time is always important to us Jim, and we would like to avoid any delay in getting clearance from you on the above material.

Sincerely,

Ed Finkel

EF/cc

A00315

JFD ELECTRONICS CORPORATION

15th Avenue at 62nd Street, Brooklyn N. Y. 11219 • Phone 212 DE 1-1000 • TWX-NY25040

U. of I. FOUNDATION
SEP 16 '64

September 14, 1964

University of Illinois Foundation
University of Illinois
Champaign, Illinois

Attention: Mr. James Colvin

Re: Copy Clearance for LPV Antennas

Dear Jim:

Following up my letter of August 12, 1964, listed below are the phrases used in our commercials, magazines and trade papers.

I would appreciate your reviewing them and clearing these so they can be used in any future ads we will prepare.

Commercials, Magazines and Trade Papers

Developed from Research Performed at the Antenna Laboratires of the University of Illinois

Developed from Research Performed at the University of Illinois Antenna Laboratories.

Adapted from the Famous Satellite Tracking Antenna Design of the Antenna Research Laboratories of the University of Illinois.

JFD ELECTRONICS ANTENNA LABORATORY EMPLOYS INDUSTRY'S HIDDEN RESOURCE -- Forms Alliance with the University of Illinois; New Laboratory Established under the Direction of Professor Paul E. Mayes, an Antenna Authority.

A00215



JFD Canada, Ltd., 81 McCormack Street, Toronto, Ontario, Canada

JFD Electronics-Southern, Inc., Oxford, North Carolina 27565
JFD International, 64-14 Woodside Ave., Woodside, New York 11377

At Work on the New Frontiers of Communications

JFD ELECTRONICS CORPORATION

[illegible] 16th Avenue at 62nd Street, Brooklyn N. Y. 11219 • Phone 212 DE 3-1000 • [illegible]

Mr. James Colvin (Cont.)

Commercials, Magazines and Trade Papers

In fact, the LPV was developed by some of the same scientists at the Antenna Research Laboratory of the University of Illinois who designed the conical spiral antenna used in the Transit Satellite.

For more than 8 years, a group of antenna scientists at the Antenna Research Laboratory of the University of Illinois has been experimenting with vhf and uhf antennas that have no theoretical limitations on bandwidth - are frequency-independent.

Please try to get your answer to me on the above as soon as possible.

Trade ads are always under tight schedules and we would not like to miss any deadlines now that we are coming into our season.

Sincerely,

Ed Finkel

EF/ss
cc-S. Faber
S. Smith

A00220

X619

224 Illini Union · Urbana, Illinois 61803

# IVERSITY OF ILLINOIS FOUNDATION

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO._____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Mr. Ed Finkel
JFD Electronics Corporation
15th Avenue at 62nd Street,
Brooklyn, N w York 11219

Dear Ed:

I regret that I have not answered your September 14 letter sooner.

Under "Commercials, Magazines and Trade Papers" we approve the first three paragraphs. These are as follows:

"Developed from Research Performed at the Antenna Laboratories of the University of Illinois."

"Developed from Research Performed at the University of Illinois Antenna Laboratories."

"Adapted from the Famous Satellite Tracking Antenna Design of the Antenna Research Laboratories of the University of Illinois."

We object to the fourth paragraph because, although you have been working in cooperation with the University, I think this slogan gives the wrong impression. The paragraph I refer to is the following:

"JFD ELECTRONICS ANTENNA LABORATORY EMPLOYS INDUSTRY'S HIDDEN RESOURCE -- Forms alliance with the University of Illinois; New Laboratory Established under the Direction of Professor Paul E. Mayes, an Antenna Authority."

So far as the next paragraph is concerned the one which begins: "In fact, the LPV . . ." we do not believe this is quite accurate and would like to have you change it as follows:

"In fact, the LPV concept was developed at the Antenna Research Laboratories of the University of Illinois which has given birth to such other space-age designs as the spiral antenna used on the Transit Satellite."

A00223

X 1319-a



The next paragraph is perfectly satisfactory. It reads:

"For more than 8 years, a group of antenna scientists at the Antenna Research Laboratory of the University of Illinois has been experimenting with vhf and uhf antennas that have no theoretical limitations on bandwidth - are frequency-independent."

With all good wishes,

Cordially yours,

James C. Colvin
Executive Director

JCC:pw

cc: Professor Paul Mayes
Mr. Samuel B. Smith

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. _____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

JFD

# JFD ELECTRONICS CORP.

RECEIVED
OCT 6 1964
MERRIAM, SMITH & MARSHALL

October 5, 1964

University of Illinois Foundation
University of Illinois
Champaign, Illinois

Attention: Mr. James Colvin

Re: Copy Clearance for
LPV Antennas

Dear Jim:

Here is a listing of the phrases used in the last category, JFD Product literature.

4. JFD PRODUCT LITERATURE

Brings the acknowledged Log-Periodic design of the Antenna Research Laboratories of the University of Illinois to a new peak of performance.

The Log-Periodic concept is the result of five years of intensive electronic studies at the Antenna Research Laboratories of the University of Illinois and JFD. Located in Champaign, Illinois (home of the University of Illinois), the vast new JFD research center is the largest and most complete of its kind.

Adapted from the Antenna Research Laboratories of the University of Illinois.

The first UHF antenna design based on the patented Log-Periodic LPV formula of the Antenna Research Laboratories of the University of Illinois.

LPV...from the Antenna Research Laboratories of the University of Illinois.



A00346

JFD ELECTRONICS CORP.

October 5, 1964

Mr. James Colvin (Cont.)

4. JFD PRODUCTS LITERATURE (Cont.)

The first TV/FM antenna based on the geometrically-derived Logarithmic-Periodic scale developed by the Antenna Research Laboratories of the University of Illinois for satellite telemetry.

Soon! From the Antenna Research Laboratory of a leading University a mathematical dream becomes an engineering reality.

Designed according to the revoluntionary new log periodic antenna formula of the Antenna Research Laboratories of the University of Illinois.

The first UHF antenna adapted from the patented Log-Periodic LPV formula of the Antenna Research Laboratories of the University of Illinois.

Developed by the University of Illinois Antenna Laboratory-now serving in Satellite Telemetry-Adopted to TV by JFD.

Significant New Principles Developed for Satellite Tracking, Space Telemetry and Military Communications by University of Illinois Antenna Research Laboratory lead to new High-Gain All-Channel Antenna "Comparable to a Yagi Array" across the entire band.

Conceived by the University of Illinois*....
Proved-Out in Air Force Satellite Tracking....
Licensed and Developed for Home Use by
JFD Electronics....



A00347

JFD ELECTRONICS CORP.

Mr. James Colvin (Cont.)

4. JFD PRODUCTS LITERATURE (Cont.)

Created by the Antenna Research Laboratories of the University of Illinois®-
Principles Utilized in Air Force Satellite Tracking and Telemetry-
Exclusive from JFD Electronics-

Again, would you please review them and let me know which we may continue to use for the future.

I take this opportunity to thank you for your patience and cooperation in resolving this problem.

Sincerely,

Ed Finkel

EF/ss
cc-S. Faber
S. Smith

A 535

224 Illini Union · Urbana, Illinois

UNIVERSITY OF ILLINOIS FOUNDATION

October 14, 1964

RECEIVED
OCT 15 1964
SHERMAN, SMITH & MARSHALL

Mr. Ed Finkel
JFD Electronics Corporation
15th Avenue at 62nd Street
Brooklyn, New York 11219

Dear Ed:

I meant to answer your October 5 letter before this but I wanted to check the statements with both Professors Jordan and Mayes and they have been very much involved in an Electrical Engineering meeting this week which kept me from getting together with them.

I am sending you the combined opinion of Mr. Jordan, Mr. Mayes and Mr. Samuel B. Smith, in which I concur.

Page 1 of your letter, paragraph 1 is satisfactory.

We ask that you eliminate paragraph 2. I think it can be rephrased but Mr. Jordan objects to it because it indicates that the entire research program was designed for the benefit of JFD. Why don't you try this one over again?

Paragraph 3. Would you please change it to read, "Adapted from research results of the Antenna Laboratory of the University of Illinois."

Paragraph 4. This is troublesome because of the use of the word "patented" and Mr. Smith tells me there are legal reasons why this should not be used.

Paragraph 5. We should like you to change it to read, "LPV -- is designed from the Antenna Research Laboratory of the University of Illinois." The reason we suggest this is that, originally worded, it implies that the Foundation is in the manufacturing business.

Page 2, paragraph 1. We should like to have it changed to read, "The first TV/FM antenna based on the geometrically-derived Logarithmic-Periodic scale developed by the Antenna Research Laboratories of the University of Illinois and used in satellite telemetry."

Paragraph 2. We ask you not to use this one. It is good advertising copy. I think it could be rewritten and modified.

Paragraph 3 is satisfactory.

A00349

Paragraph 4 is untrue. The Log-Periodic LPV formula is not patented. Patents are issued only on the structure which was based upon the principle covered by the formula. This paragraph seems objectionable from a legal standpoint. Why don't you rewrite it and resubmit?

Paragraph 5 is satisfactory.

Paragraph 6. We should like to have rewritten as follows: "Significant New Principles Developed by the University. . . . .etc."

Paragraph 7 is not true. It wasn't the University which conceived the idea but the people in the Antenna Laboratory. You may want to resubmit a paragraph similar to this.

Page 3. The paragraph on this page is satisfactory.

Best regards!

Cordially yours,

James C. Colvin
Executive Director

JCC:pw

cc: Mr. Samuel B. Smith

# What does JFD® have that other TV antenna manufacturers wish they had?

FILED
AUG 27 1969
CLERK, U.S. DISTRICT COURT
A. WAGNER, JR.
CLERK

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 31
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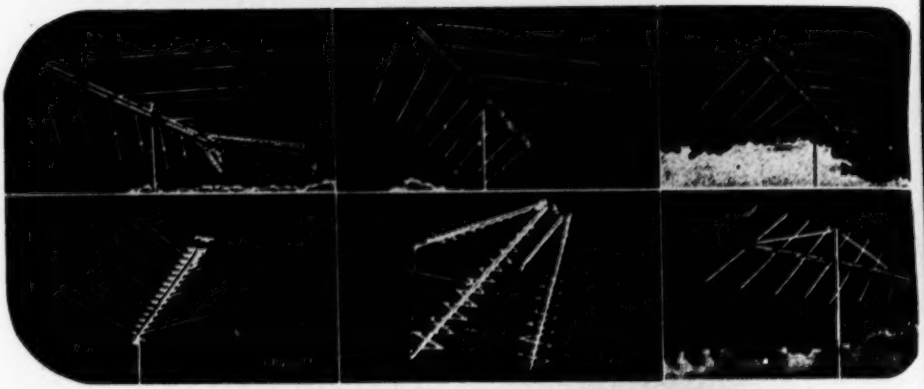
OFFICIAL COURT REPORTER



*the* JFD® LPV® COLOR LOG PERIODIC

# ELECTRONIC TECHNICIAN

WORLD'S LARGEST ELECTRONIC TRADE CIRCULATION

AUGUST 1966
VOL. 84 NO. 2

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## Cover

The 'lonely girl on the beach' is passing away with the electron tube. She 'totes' her solid-state TV from-car-to-beach and, between cool dips, diverts her thoughts with a variety of absorbing telecasts.

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*How another successful TV-radio service-dealer conducts his modest operation*

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*How you can replace thousands of transistor types with a couple of dozen or less*

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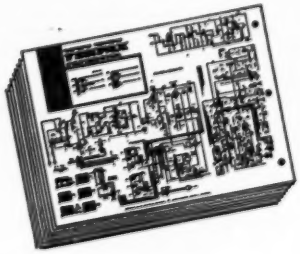
## TEKFAX — 16 PAGES OF THE LATEST SCHEMATICS



Group 168 — August • 1966

DUMONT: TV Chassis 120837-A, 120846-B, 120647-B

RCA VICTOR: TV Chassis KCS162 Series

SEARS-SILVERTONE: TV Models 7110, 7111, 7114, 7138, 7131

SYLVANIA: Color TV Chassis DO5 Series

WESTINGHOUSE: TV Chassis V-2496 Series

ZENITH: Color TV Chassis 23XC36

# Mr. Dealer:

Don't let other antenna makers "snow" you with claims of how **their** antenna "break-throughs" work so sensationally you hardly need a TV set to get a picture.

They've got little choice.

Ever since the LPV Color Log Periodic was introduced by JFD back in '62, our competitors' engineers have been going around in circles. They've copied it down to the rivets. They've camouflaged their use of the log periodic principle with terms such as "energy distribution."

They've imitated its name by calling theirs "V-log," "Super-log" nd ..... -log.
(fill-in-yourself)

hey've tried to equal its performnce with "half-size" compacts—ut you can't send a midget to do man's job—this just doesn't ork.)

ey still don't know whether to ock it . . . fight it . . . join it . . . how to live with it.

e say **the proof of it all is the picre your antenna delivers to your stomer's set.** That is where the D LPV Color Log Periodic conlusively demonstrates its basic erformance superiority.

f you're looking to give your cusomers the **finest** and **truest** color . . **crispest** black & white . . . **more** HF and UHF channels . . . even etter FM **stereo**—don't compronise **your** professional reputation vith "antenna-compromises." Rely n the patented JFD LPV Color Log eriodic as do so many tens of housands of knowledgeable serce-dealers.

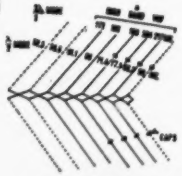
Ve don't expect you to take **our** ord for it either. Let the **picture** nd your **profits**) be the proof.

## Exactly WHAT the JFD LPV Color Log Periodic has that other so-called antenna "break-throughs" would like to have!

• ONLY the JFD LPV delivers genuine **frequency-independent** performance. The **entire** antenna (not part of the antenna as in other ordinary antennas) responds to **every** channel.

$$\frac{L_{(n+1)}}{L_n} = \tau$$

• ONLY the JFD LPV follows the **patented log periodic** design of the University of Illinois Antenna Research Laboratories.



• Only the JFD LPV uses **Cap-Electronic** (capacitor-coupled) elements. This permits (1) precise and independent tuning for optimum performance in **both** fundamental **and** harmonic modes—**plus** (2) increased capture area—**plus** (3) directors tuned to perform on **all** bands, not just one. The result is **higher** gain, **narrower** directivity, **higher** front-to-back ratios for brilliant color, better-than-ever black & white—on channels 2 to 83.

**LIFE** **NATIONALLY ADVERTISED IN LIFE.** Month after month, 32 million readers of LIFE are being exposed to the reasons why the JFD LPV works best.

**COLORFULLY ADVERTISED OVER TELEVISION.** Spectacular motion-picture commercials in full-color are pre-selling millions of present and prospective color TV owners.

**25 DIFFERENT LPV LOG PERIODICS TO CHOOSE FROM.** Interested in VHF? . . . UHF? . . . VHF/UHF/FM? Whether it's just **one** band or **all**, town or country, you get the precise antenna-answer when you make it an LPV Color Log Periodic. Interested in more facts? Just write us.

**MERCHANDISED IN DEPTH.** Banners, direct mail, newspaper mats, radio/TV commercials . . . you name it JFD's got it to help you sell your way to top antenna profits.

• **A WORD ABOUT OUR PATENTS . . .** Eleven different U. S. patents and patents pending embrace the scientific advances of the JFD LPV—more than any other outdoor TV antenna. Our competition's attorneys are burning the midnight oil trying to find loopholes and ways to circumvent this patent protection which assures you of getting the only genuine antenna designed according to the original patented log periodic design of the famous University of Illinois Antenna Research Laboratories.

LICENSED UNDER ONE OR MORE OF U.S. PATENTS 2,958,081, 2,985,879, 3,011,169, 3,109,180, 3,140,176, 3,210,767, RE. 25,740 AND ADDITIONAL PATENTS PENDING IN U.S.A. AND CANADA. PRODUCED BY JFD ELECTRONICS CORPORATION UNDER EXCLUSIVE LICENSE FROM THE UNIVERSITY OF ILLINOIS FOUNDATION

**AT THE MOMENT OF TRUTH THE PICTURE IS THE PROO**
**WHY JFD LPV COLOR LOG PERIODICS WORK BEST!**

# JFD ELECTRONICS CORPORATION

15th Avenue at 62nd Street, Brooklyn, N.Y. 11219
JFD International, 64-14 Woodside Ave., Woodside, N.Y. 11377
JFD Canada, Ltd., Canada

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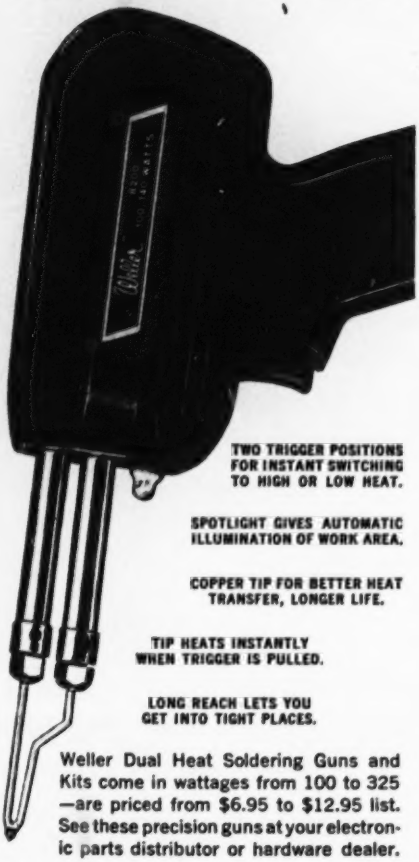
# No wonder soldering is easiest with a

# Weller®

## DUAL HEAT SOLDERING GUN



TWO TRIGGER POSITIONS FOR INSTANT SWITCHING TO HIGH OR LOW HEAT.

SPOTLIGHT GIVES AUTOMATIC ILLUMINATION OF WORK AREA.

COPPER TIP FOR BETTER HEAT TRANSFER, LONGER LIFE.

TIP HEATS INSTANTLY WHEN TRIGGER IS PULLED.

LONG REACH LETS YOU GET INTO TIGHT PLACES.

Weller Dual Heat Soldering Guns and Kits come in wattages from 100 to 325 —are priced from $6.95 to $12.95 list. See these precision guns at your electronic parts distributor or hardware dealer.

**WELLER ELECTRIC CORP., EASTON, PA.**

*WORLD LEADER IN SOLDERING TECHNOLOGY*

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# EDITOR'S MEMO

### Serving Best

There's an old saw about "He who tries to serve everyone serves no one."

ELECTRONIC TECHNICIAN has been urged from time to time to include broadcast engineering, circuit designing, medical electronics, lab engineering, ham radio and many other specialized areas of the electronics field in its editorial content. We've even been urged to include do-it-yourself construction type articles.

The electronics field is very broad and many magazines now cover various specialized areas of that broad field. We intend to continue serving professional home-entertainment product service-dealers and technicians in those areas in which they derive their total incomes. Any magazine that attempts to serve *everyone* will fail to serve *anyone* — and it doubtful if such a magazine would be around very long.

We have been urged to include radio, CB, auto radio, tape recorder, Hi Fi and other equipment schematics in the 16 pages of TV schematics which appear every month in ET. But an overwhelming majority of readers have repeatedly indicated that every inch of TEKFAX is extremely valuable to them as it is. They have requested that we do not cut, mangle and water down these pages with other schematics. There are literally thousands of other schematics which cover radios, phonograph amplifiers, Hi Fi equipment, CB radios, regular two-way equipment and other gear.

We couldn't do justice to any one schematic area if we ran a "potpourri" of schematics covering the entire home-entertainment and communications industry. Because of the number of schematics involved, we can do justice only to the TV area — and we are now doing just that.

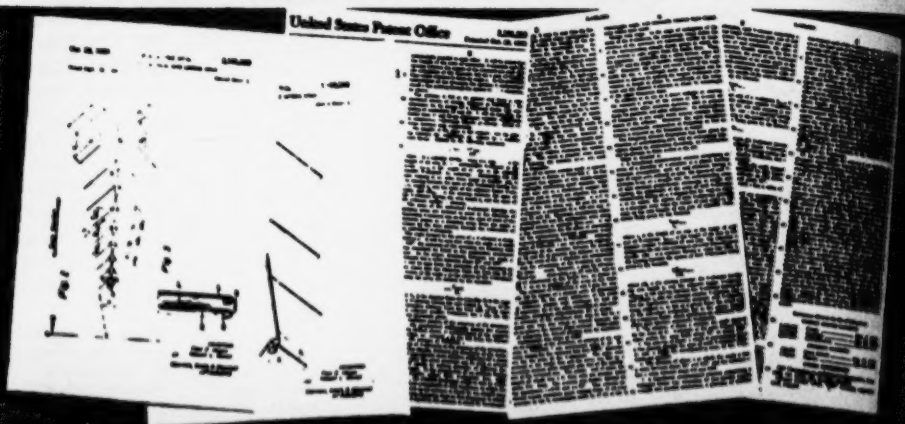
During the past year or so we have improved the value of TEKFAX by including important scope waveforms, parts lists, service notes and other important data. We have published the latest solid-state and color TV schematics which every technician will soon need. Those who have been receiving ET for the past five years or longer now have close to 90 percent of all the basic schematics needed for day-to-day work.

ELECTRONIC TECHNICIAN is sensitive to the needs of its readers. We will continue to serve those needs to the best of our ability.

RADIO & TELEVISION WEEKLY February 10, 196

(2)
UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO
DOROTHY L. GRACKENBURY
OFFICIAL COURT REPORTER

# UNIVERSITY OF ILLINOIS MAYES-CARRELL PATENT ON LOG-




G PERIODIC BACKWARD WAVE ANTENNA ARRAY U S PAT
3,108,280. OF PAUL E. MAYES AND ROBERT L. CARRELL
SIGNORS TO THE UNIVERSITY OF ILLINOIS FOUNDATION

## U.S. PATENT DISCLOSES THAT NEW LOG-PERIODIC

*(Col. 1, lines 10-12 of Log-Periodic Patent)*

Has Unidirectional radiation patterns that are essentially -ndependent of frequency over wide bandwidths."

*(Col. 2, lines 62 66 of Log Periodic Patent)*

"Increases directivity*** permits more effective utilization of antenna since the same structure can be used in several frequency modes to achieve coverage of different frequency bands."

*(Col. 3, lines 73-75; Col. 4, lines 1 and 2)*

"This antenna exhibited typical directivity gains ranging from 12 db over isotropic in the 3/2 wavelength mode to 17 db in the 7/2 wavelength mode with essentially constant input impedance within each mode."

*(Col. 4, lines 21 and 22)*

"Moreover, the input impedance remains essentially independent of frequency."

*(Col. 4, lines 40-43)* "***given by the formula $\frac{L_{n+1}}{L_n}$

ONLY THE JFD LOG PERIODIC LPV OPERATES ACCORDING TO THE PATENTED
OG PERIODIC CELLULAR FORMULA $\frac{L_{n+1}}{L_n}$ TO PROVIDE FLAWLESS COLOR,
LACK AND WHITE TV. & FM S

10, 1964 RADIO & TELEVISION WEEKLY

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. [redacted]
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

# FOUNDATION AWARDED PERIODIC V-ANTENNA—JFD LPV

U S DEPARTMENT OF COMMERCE
PATENT OFFICE
WASHINGTON

Paper No. 9

[redacted]

| | | |
|---|---|---|
| Applicant: Harris Greiser | | |
| Ser. No. 63,532 | | MAILED |
| Filed October 19, 1960 | | 1962 |
| For DUAL BAND TELEVISION ANTENNA | | PATENT OFFICE 65 |

Please find below a communication from the EXAMINER in charge of this application.
Commissioner of Patents.

Responsive to amendments filed January 2, 1962 and September 12, 1962.

References made of record

Kandoian 2,479,629 Oct. 23, 1947

IRE Transactions on Antennas and Propagation, Vol. AP-8, No. 3, pages 328-333, April 1960. Published. Library

Claims 2, 6, 7, 11-18, 20 and 21 are rejected as unpatentable over the patent to Kandoian in view of the above cited IRE article. Fig. 1 shows a coplanar array of dipoles of decreasing length in a direction towards the feed point, a transposition harness interconnecting the dipoles. The proportional energy radiation away from the feed point described on the top of page 3 of the reference and this is considered the equivalent of the proportional energy feature stressed in the claims. Regarding claim [illegible] "substantially equally spaced" is too vague [illegible] over the Isbell antenna.

Claims [illegible] are rejected as unpatentable [illegible]

Claims 2, 6, 7, 11-18, 20, and 21-27 are rejected.

[illegible]

## DO NOT BE MISLED BY LOG-PERIODIC IMITATIONS OR MISLEADING PATENT CLAIMS

Professor Paul Mayes of the Antenna Research Laboratories of the University of Illinois, originator of the log-periodic V-dipole antenna concept

**THERE IS ONLY ONE GENUINE PATENTED LOG-PERIODIC V-ANTENNA—THE JFD LPV!**

**JFD LPV**

Only JFD is licensed exclusively by the University of Illinois [illegible] like the patented Log-Periodic LPV and all other Log-Periodic type TV [illegible] antennas

No other so-called Log-Periodic antenna can work like the **JFD** [illegible] dic LPV because **only JFD** uses the original **patented** Log Periodic [illegible] of the Antenna Research Laboratories of the University of Illinois. Ask [illegible] FD LPV and see why At the Moment of Truth, The Picture [illegible] the Proof—that [illegible] V works **best!** Now in stock at your JFD distributor

*JFD will be glad to send you a copy of the official Log Periodic Antenna U.S. Patent [illegible] and comparison*

**JFD**

**JFD ELECTRONICS CORPORATION**
15th Avenue at 62nd Street, Brooklyn, N.Y.

JFD Electronics Southern [illegible]
JFD International, 64 [illegible] Avenue, [illegible]
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401-444 W. Hastings Street, [illegible]

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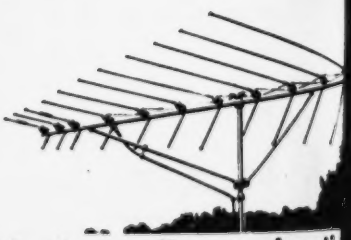
# The Technical Press...The News Press... The Consumer Press...The Trade Press

NEVER BEFORE HAVE
SO MANY
SO ACCLAIMED
A NEW TV ANTENNA
CONCEPT ...

JFD
LOG-PERIODIC
LPV $\frac{L_{(n+1)}}{L_n} = \tau$



the antenna with the college educati

# HOT NEWS TRA

**Popular Science • Chicago Tribune • Microwave Journal • Electronic Industries • Home Furnishings Daily • Radio Electronics • PF Reporter • Electronic Technician • NEDA Journal • Radio and TV Weekly • Modern Electronic Service Dealer • Electronic Distribution • NATESA Scope • Electronic and Appliance Specialist**

And that news is the JFD log periodic TV/FM antenna. News of its remarkable performance is sweeping the country. Servicemen, installers, engineers, and distributors by the tens of thousands have seen what the LPV can do—and now they are JFD log periodic LPV fans for life.

No wonder the editors of electronics publications have accorded the LPV more news coverage than any TV qr FM antenna has ever received. News stories, field reports, full length technical articles are telling the world about the new antenna discovery and how the antenna research laboratories of the University of Illinois and JFD helped design it.

***NOW'S THE TIME TO JOIN THE EVER-INCREASING NUMBER OF SERVICE DEALERS THROUGHOUT THE NATION WHO ARE FEATURING, PROMOTING AND SELLING JFD LOG-PERIODIC LPV ANTENNAS– FOR COLOR AND BW/TV–FM STEREO!***

**JFD LPV** $\frac{L(n+1)=\tau}{Ln}$

PROFESSOR PAUL MAYES
. . . designs new TV antenna

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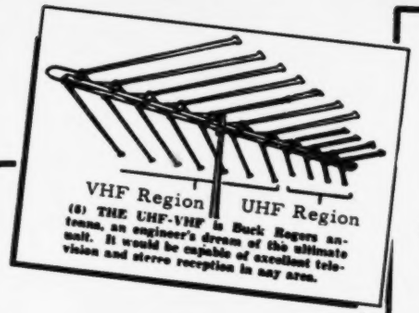


(8) THE UHF-VHF is Buck Rogers antenna, an engineer's dream of the ultimate built. It would be capable of excellent television and stereo reception in any area.

## TV Antenna Designed By UI Men On Sale Soon

By DAVE YOUNG
News-Gazette Staff Writer

An improved television antenna, designed by a University of Illinois professor and one of his students, will be on the market in about two weeks.

Paul Mayes, UI associate professor of electrical engineering, said Saturday that one local distributor reported the antenna was promised from the manufacturer next week.

Mayes designed the antenna in cooperation with Robert L. Carrel, now with Collins Radio Co., Dallas, Tex. The invention was disclosed in the summer of 1958, he said.

The antenna is being manufactured by JFD Electronics Corporation, Brooklyn, N.Y.

According to Mayes, the antenna will be able to pick up signals from out-of-town stations. However, weather and antenna locations are important factors in distant reception, and signal strengths from distant stations vary widely with time of day.

The outstanding trait of the new design is the fact that the performance of the antenna does not depend upon the channel being received. Most fringe area television antennas in use today are patterned after the Yagi design which has only a few elements which are connected to the receiver, he said. The performance of the Yagi changes with frequency, however, so that it receives some channels better than others, he explained.

Mayes' and Carrel's invention is an outgrowth of research in frequency — independent antennas which has been under way at the University of Illinois Antenna Laboratory since 1954. In the new antenna most of the elements are connected to the receiver and vary in length in a way which minimizes variations in performance.

Under very favorable circumstances Champaign-Urbana viewers might be able to pick up signals from stations as far away as Chicago, Indianapolis, and Terre Haute. Mayes said, however, that such reception would be subject to many external conditions and will vary from day to day.

The new antenna is V-shaped. It consists of several aluminum rods hooked into metal rods running down the center of the antenna. The antenna will sit on housetops like the varieties in current use.

Mayes said he is working on a new antenna for ultra high frequency signals. He said that frequency independent UHF antennas will be increasingly important in view of recent federal legislation which requires all newer television sets to be equipped for receiving both VHF and UHF channels.

The federal law becomes effective in 1964.

The VHF antenna was designed in the UI Antenna Laboratory, which is part of the electrical engineering department.

The UI Foundation has applied for patents and licensed the JFD organization to manufacture the ante...na.

Reprinted from Chicago Daily Tribune January 23, 1962

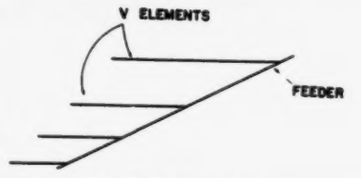


Figure 18 — Method of tilting elements in V arrays to achieve beam tilt in H-plane — side view of LPV array with elements tilted in H-plane.

(3) The half-length $h_1$ of the largest element should be approximately one-quarter wavelength at the lowest frequency desired. Lengths of all other elements are determined by using the scale factor $\tau$ and the spacings between elements are determined by $\sigma$.

(4) The nominal input impedance in the $\lambda/2$ mode will be 30 to 70 per cent below the impedance of the feed line depending upon $\tau$, $\sigma$, and the thickness of the elements used. The impedance increases as the loading effect of the elements decreases, i.e., as the density of elements decreases. The impedance in the higher modes is higher than that in the $\lambda/2$ mode.

The LP resonant-V array provides essentially frequency-independent coverage of each of several frequency bands. If the desired bands are small in width, the frequency variations of the uniform periodic array may not be objectionable, thus permitting a simplification of the structure. Antennas designed according to these concepts should find application whenever coverage of several widely dispersed frequency bands is desired or when the additional directivity achieved in the higher mode operation is required.

Figure 19 — An LPV antenna for all-channel VHF television receiving.

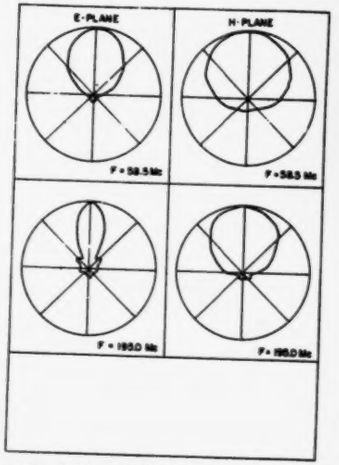


Figure 20 — Low-band and high-band radiation patterns of LPV antenna for VHF television.


### Acknowledgment

Dr. Robert L. Carrel was associated with the author in the early investigations of the log-periodic resonant-V antennas. The basic work was supported by the USAF through contract AF33(616)-6079 with Wright Air Development Division. The design and construction of the television receiving antenna was made possible by a grant from the University of Illinois Foundation. Patents are pending.


### References


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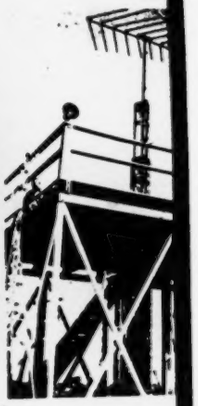

Above, Professor Paul E. Mayes of the University of Illinois and Ed Fichal of JFD Electronics inspect feedline of the JFD Antenna Research and Development Center. Above right, a long-periodic LPV-6 undergoes gain test atop 135-foot tower at Center. Right, a JFD log-periodic LPV-11 being field-tested in a Philadelphia suburb.

## New Concept In Antennas

### Log-periodic "LPV" antenna is result of JFD application of basic research developed at the University of Illinois

A series of radically new television antennas that offer high gain, sharp directivity, and constant impedance across the complete VHF television and FM bands have recently been introduced by JFD Electronics Corp., one of the world's largest producers of TV antennas.

The log-periodic "LPV" antennas reflect the first genuinely new concept injected into the field of TV antenna design in several years. Used in space telemetry, satellite tracking and military communications, the log periodic principle is the result of over five years of intensive research and development by scientists in the Antenna Research Laboratory of the University of Illinois. Adapted for television by the JFD antenna engineering staff, the log periodic "LPV's" frequency independent characteristic yields a high level of gain uniformly over the entire VHF and FM bands.

Verified gain measurements indicate that a single LPV antenna produces as much gain on all channels as a complete set of comparable sized single-channel yagis. Its impedance, polar patterns, and front-to-back ratios are virtually uniform. Unlike conventional antennas, the log periodic LPV uses a larger group or "cell" of driven dipoles actively engaged in stepping up gain on every low and high band channel.

Each antenna in the "LPV" series consists of an array of resonant V dipoles interconnected by transposed phasing harnesses, constituting a series of "cells." The size of each cell (or group of dipoles) differs from the one before it by a logarithmic factor. In operation, each received channel furnishes maximum signal to the cell corresponding to its particular half wavelength. For the high band frequencies, additional signal for each channel is furnished by operation on the third harmonic mode. The consequently large number of dipoles contributing their signals in proper phase and at constant impedance, accounts for abnormally high gain and expanded bandwidth. In brief, more working elements operate on every channel.

The constant impedance, regardless of frequency, is another unique feature of the log periodic concept. This frequency independent characteristic overcomes the heretofore incompatibility of high gain, high front-to-back ratio, narrow unidirectional polar pattern, and broad bandwidth.

Each of the JFD antenn... LPV series has been desi... specific TV reception area... locations to the farthest ... LPV-4 and LPV-6 have fo... cells respectively, and ... mended for use within 30 ... from the transmitter. For ... mile reception, the LPV-8 ... 11 with seven and nine ... respectively, are suggested ... the latter include direct... sharper forward polar patt... higher frequencies. Two m... complete the series, the L... 13 active cells and one di... the LPV-17 with 15 activ... two directors for 150 and ... reception, respectively.

All LPV antennas featu... clusive JFD "Flip-Quik" ... by, which all elements click ... on the cross-arm in minute... of new "tank-turret" bra... extra-heavy gauge, one-it... aluminum boom provides t... needed to withstand high ... heavy snow and ice loadi... ments are gold anodized ... corrosion and are reinforc... bracket connections with ... aluminum inserts.

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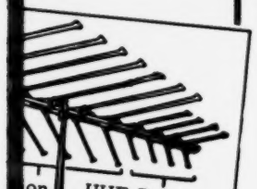

on UHF Region

VHF is Buck Rogers an-
's dream of the ultimate
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reception in any area.

## Designed By
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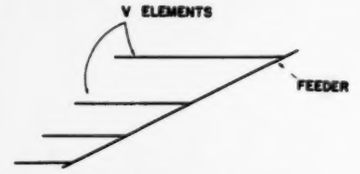


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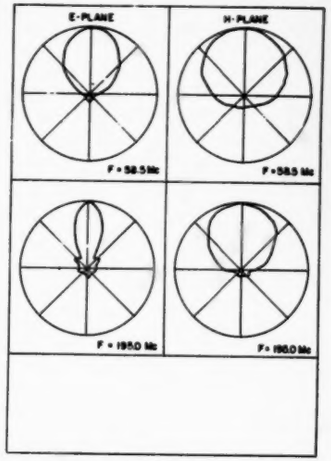


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The constant impedance, regardless of frequency, is another unique feature of the log periodic concept. This frequency independent characteristic overcomes the heretofore incompatibility of high gain, high front-to-back ratio, narrow unidirectional polar pattern, and broad bandwidth.

Each of the JFD antennas in the LPV series has been designed for a specific TV reception area, from city locations to the farthest fringe. The LPV-4 and LPV-8 have four and six cells respectively and are recommended for use within 50 to 75 miles from the transmitter. For 100 to 125 mile reception, the LPV-8 and LPV-11 with seven and nine active cells respectively, are suggested. Each of the latter include directors for a sharper forward polar pattern at the higher frequencies. Two more models complete the series, the LPV-14 with 13 active cells and one director, and the LPV-17 with 15 active cells and two directors for 150 and 175 mile reception, respectively.

All LPV antennas feature the exclusive JFD "Flip-Quik" construction by which all elements click into place on the cross-arm in minutes by means of new "tank-turret" brackets. An extra-heavy gauge, one-inch square aluminum boom provides the strength needed to withstand high winds and heavy snow and ice loading. All elements are gold anodized to prevent corrosion and are reinforced at vital bracket connections with heavy wall aluminum inserts.

Form No. 3761LP Mfrs in U. S. A.

**what's new**

ELECTRONICS

# Powerful New Antenna for TV and FM, too

**Early research model** of the LPV is being adjusted here by the designer, Prof. Paul Mayes. This version worked fine, but turned out to be too expensive for mass production.

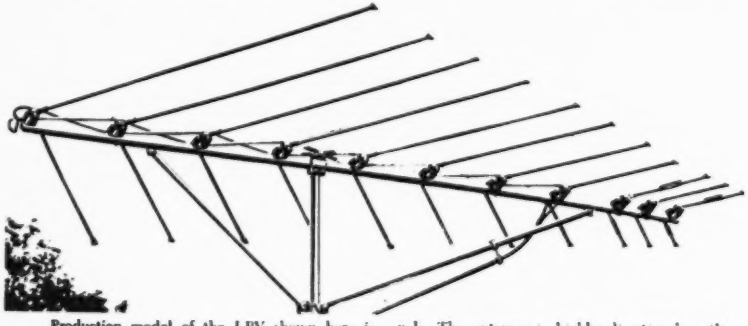
THE wraps have just come off a remarkable new antenna. It will give TV viewers and FM listeners the benefit of know-how engineers gained in licking the problems of communicating with satellites.

This relatively compact antenna, the LPV, will feed your TV or FM stereo receiver an exceptionally strong signal over the entire VHF band (Channel 2 through 13 and FM stereo). Furthermore, it rejects ghosts and interference reaching it from the back and sides, as positively as a long-john yagi (which can be made to work efficiently on only one channel).

New to consumer TV, but basic to many space-communications antennas, the principle of operation is known to engineers as the *log periodic* principle. (We'll get to the V in LPV in a moment.) In fact, the LPV was developed by some of the same scientists at the Antenna Research Laboratory of the University of Illinois who designed the conical spiral antenna used in the Transit satellite. It is, mathematically, a flattened version of that design.

The LPV looks like the skeleton of a streamlined flounder. The elements are longest at the rear and get successively shorter toward the front. They are tilted forward to make a V—that V in LPV.

Even if you're not a mathematician, you can get a rough idea of how the LPV works if you'll think of a long escalator with people hopping on at each of several floors. The signal picked up by each set of elements is continuously passed along a zig-



**Production model** of the LPV shown here is the LPV-11, designed for fringe areas. The 11 sets of elements (or cells) include two directors in front for sharper response on the high channels. The antenna is highly directional, with minimum response to the sides and back. Uniformity of gain over complete VHF band is said to give better color reception.

zag network of bars to the antenna terminals. The trick is to keep all the waves adding together in phase. The result is a whopping big signal sent down to the TV set. The LPV achieves this by arranging the elements according to a log-periodic formula that fools the signals into acting as though the separate elements were actually a huge, continuous spiral, constantly in phase.

JFD Electronics, Brooklyn, N. Y., makes the commercial version of the LPV in six models to suit different receiving conditions. The smallest and least expensive, the LPV-4, has four sets of elements—adequate for high signal areas close to TV stations. The largest is the LPV-17 with 17 sets of elements; it would ordinarily be used for far fringe reception or areas where there are particularly troublesome local conditions.—*Charles Tepfer.*

Reprinted courtesy of **Popular Science** Monthly ©1963 by Popular Science Publishing Company, Inc.

# U. I. RESEARCH TRIUMPHS IN ELECTRONICS

## New Antennas Boost to Communications

***(Fourth in a series of reports by a reporter who roamed the campus of the University of Illinois at Urbana to find out what is new in the world of scholarship.)***

BY FRANK HUGHES

Scientific research at the University of Illinois has scored a major advance in the field of electronics.

The triumph came in the antenna laboratory at the college of engineering in Urbana. There, in the upper floor and on the roof of an old building tucked along the side of Burrell street, more than 10 years of research finally paid off in three unique antenna designs for radio and television.

### Puzzles Since 1886

They solve problems which have baffled communications engineers since 1886, when Heinrich Rudolph Hertz discovered the existence of electromagnetic waves, the heart of all radio and TV communication.

A Vee log-periodic antenna.

The antenna laboratory was founded by Dr. E. C. Jordan, head of the electrical engineering department of the college, and is directed by Dr. Georges A. Deschampes. Among the professors who have contributed heavily to the creation of the new antennas are Doctors John D. Dyson, Paul E. Mayes, R. H. DuHamel, E. M. Turner, V. H. Rumsey, R. L. Carrell, and D. E. Isbell.

The designs they have created, unique and years ahead of anything previously conceived, are the log-periodic, the log-spiral, and the Vee log-periodic. These technical sounding names describe arrays of metal rods or wires which do things for radio waves better than they ever have been done before.

### What They Accomplish

Among other things, accomplishments of the antennas are:

1. The log-spiral made possible creation of the U. of I. radio telescope near Danville, Vermilion county, which is tracking electronic emissions of the stars in a scanning pattern similar to that on the face of a television tube. Eventually it is expected to produce a picture just as good.

2. The log-periodic antenna gives a ten-fold gain over a single wire, and signals from the front are more than 100 times stronger than from the back of the array, either transmitting or receiving. While other broad-band antennas have been invented, this one has no limit in the spectrum of frequencies it will receive or transmit, except what is imposed by the space it occupies.

3. The Vee log-periodic, or Vee-periodic, which looks like the backbone and ribs of a fish, promises to revolutionize reception of television signals in fringe areas. It has enormous gain and perfectly flat resonance and impedance characteristics over the extremely wide band of television frequencies from VHF [very high frequencies] to UHF [ultra high frequencies].

### Describes Their Work

Prof. Paul Mayes, who has had a hand in the creation of all of these designs, and with Prof. Carrell developed the Vee array in 1960, described how they work in an interview with THE TRIBUNE.

Wide band antennas in the past, he said, were limited to about a two-to-one frequency ratio, from 500 kilocycles to 1,000 or possibly 1,500 kilocycles in the broadcast range and 2 to 4 megacycles in high frequency, for instance.

"The log-periodic has no theoretical limitation," he said. "With reasonable size, a 20 to 1 bandwidth is possible, and the accuracy of construction is the only limitation. The radiation pattern remains the same, also the impedance."

Constant impedance over this wide range of frequencies is vitally important, because it eliminates the necessity of cumbersome tuning networks at many points on the antenna array, and frequent adjustment of them either by costly remote-control service systems or by hand.

### Interest from Industry

The log-periodic is of tremendous interest to industry, and because of its range and simplicity many users of UHF and microwaves are testing it. The Vee-periodic, which not only will enhance the pleasure of TV listeners, but will expand the commercial market of television stations enormously, has even greater directivity and gain than the log-periodic.

The log-spiral is particularly adapted to radio telescope work. The antenna of the U. of I. radio telescope at Danville is a huge reflector trough—a ravine 600 feet long and 400 feet wide, dug to an eliptical pattern, paved, and lined with wire mesh. A 425-foot wooden truss has been erected 153 feet above the bottom of this reflector to hold 276 of the log-spiral antennas, each about two feet long and small enough to hold in both hands.

The antennas are rotated a certain number of degrees each day to cover a 15-minute arc of sky.

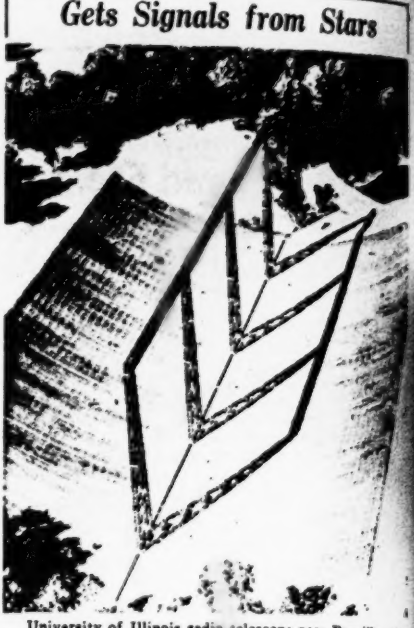
Signals from the stars strike the wire mesh reflector, are picked up by the powerful gain of the log-spiral antennas, and piped to low-noise parametric amplifiers.

### 276 Antennas Joined

A semi-conductor switch connects the 276 antennas in rapid alternation to a standard source of electrical noise, to measure the difference between the sources. The parametric amplifiers send the results thru a radiometer and into a graphic recorder. Eventually recording will be done on punched tape and processed in a digital computer.

Until Prof. Dyson, who received the patent, developed the log-spiral, and until Prof. Yuen T. Lo of the antenna laboratory designed the odd-looking cone, the radio telescope was only a dream in the minds of astronomers and engineers.

## *Gets Signals from Stars*



University of Illinois radio telescope near Danville, whose wooden truss, 425 feet long, carries 276 log-spiral antennas developed by university scientists to receive signals from the stars. (UPI Telephoto)

Reprinted from Chicago Daily Tribune, January 24, 1962

The Log Periodic V Antenna

JUNE

# Radio-Electronics

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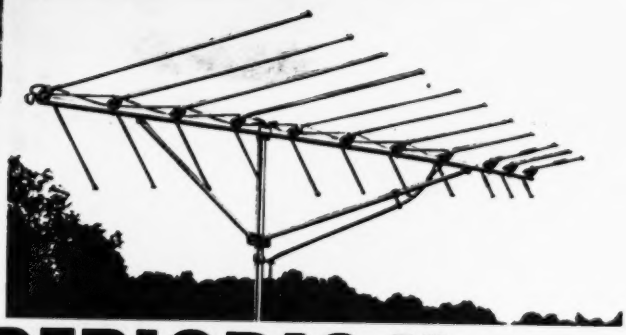


## LOG PERIODIC V

### Complete information on the new high-gain all-channel TV antenna concept

By EDWARD FINKEL*

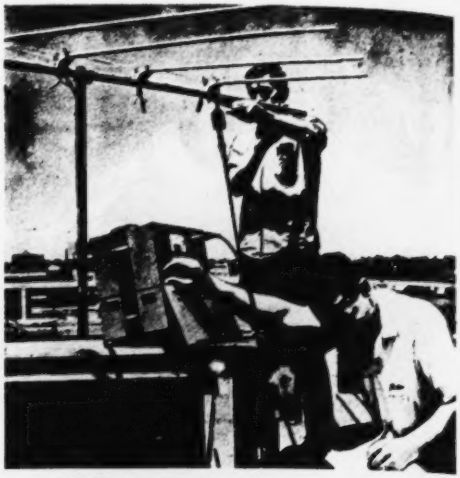
CERTAIN LIMITATIONS HAVE BEEN INherent in TV antenna design for so long that they have been accepted as axiomatic. No commercial antenna has had uniform high gain over the complete vhf TV band. It has been assumed that an all-channel antenna is not possible except by a compromise design that gives up a little bandwidth to get a little gain, or vice versa. The gain curves of modern TV receiving antennas are studded with peaks and valleys that show, only too well, how they depend on frequency.

Most antennas for fringe-area reception are based on the Yagi design. The Yagi has high gain and high front-to-back ratio. But it is essentially a narrow-band antenna—it cannot cover the entire vhf TV band from 54 to 216 mc. A simple Yagi is most effective for a single channel, a spread of only 6 mc. Modified Yagis, with dipoles cut for the center of the low and high bands and an array of various-size parasitic elements for broadening bandwidth, generally have good gain at the high end of each band and degenerate at the low end. This is the fate of *any* antenna burdened with a large number of parasitic elements. These lower the characteristic impedance at the low end of each band, and make for signal-sapping standing waves and impedance mismatches between the antenna and the transmission line.

For more than 8 years, a group of antenna scientists at the Antenna Research Laboratory of the University of Illinois has been experimenting with vhf and uhf antennas that have no theoretical limitations on bandwidth—are frequency-independent. Various experiments led Profs. V. H. Rumsey and J. D. Dyson to the log spiral antennas. Out of this research came the sharply directional, yet broad-band, conical spiral antenna now being used for satellite tracking.

* Executive vice president, sales and engineering, JFD Electronics Corp.

Prof. R. H. Du Hamel next tried and succeeded in developing a linearly polarized antenna based on the conical spiral, and Prof. Paul Mayes with R. C. Carrel and D. E. Isbell further developed this design to the point where it was basically suitable for television. JFD antenna engineers worked with the University of Illinois scientists to develop the final versions of the *log periodic V*, or LPV, antenna for television. The LPV promises to revolutionize the TV antenna field. Although it is now designed to cover uniformly both the low and high vhf TV bands and the FM band in between, a frequency spread of 4 to 1, this antenna type can easily be extended to include uhf. The unique thing about it is that within each TV band its impedance, gain, reception pattern and front-to-back ratio are virtually constant. The gain for each channel is as high as that furnished by a comparable sized, single-channel Yagi.



*Technicians checking characteristics of a prototype LPV antenna at the JFD laboratory in Brooklyn.*

**Log periodic concept**

Essentially, the LPV antenna incorporates two separate design concepts: the log periodic factor, which determines the size and spacing of the elements; the forward V shape of the elements, which permits multi-mode operation and determines its directionality. Let us first consider the periodic function.

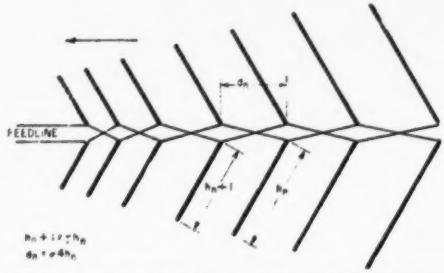



*Fig. 1—Fundamental LPV. Bandwidth and directivity are controlled by length and spacing ratios of adjacent dipoles.*

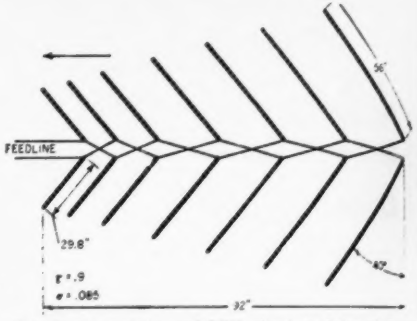



*Fig. 2—An experimental LPV, showing relation of element length and spacing.*

The basic planar log periodic antenna is an array of dipoles in which the length of each element bears a fixed ratio to the length of the preceding element. This ratio is called the *scale factor* and is designated by the Greek symbol $\tau$ (tau). The spacing between adjacent dipoles may also be fixed by a ratio, $\sigma$ (sigma). These relationships are shown in Fig. 1, where $h$ denotes element half length and $d$ represents the spacing between dipoles.

The actual values of tau and sigma were derived from many experimental models and tests and finally selected from tables which combine these test results. The directivity of the antenna increases with increasing tau, and sigma must be small to obtain higher mode (harmonic) operation, important for high-band reception. (The mode desired multiplied by sigma should equal 0.2 to 0.4.) Since, for TV, the third mode is desired (as will be explained later), a good value for sigma is .085.

Each of the dipoles in the antenna is equal to an adjusted half-wavelength at a different frequency, making the dipole resonant to that frequency. The scaling factors $\tau$ and $\sigma$ are so chosen that the desired frequency range is covered with elements whose resonances overlap. Thus, as the frequency changes, resonance moves smoothly from one dipole to the next.

Typical values of tau and sigma are 0.9 and 0.085, respectively. These in fact are the actual values used in one of the many experimental models developed in the JFD laboratories. This is a seven-element antenna, 92 inches overall, with $h_n$, the half length of the longest element, 56 inches, approximately one-quarter wavelength at channel 2. Lengths of all other elements are determined by the equation in Fig. 1. A diagram of this antenna is shown in Fig. 2.

In designing the larger LPV models it was necessary to depart slightly from the log periodic formula, to make the antennas commercially and mechanically practicable.

**Fundamental operation**

Just as the largest dipole of the LPV antenna corresponds to a half-wavelength on channel 2 many of the other dipoles more or less correspond to the half-wavelengths of the other channels in the low TV band. Although one particular dipole—the one closest to the resonant length—absorbs the greatest amount of signal at any particular received frequency, the adjacent elements also absorb signal energy. How much is shown in Fig. 3, a curve representing the distribution of current at the terminals of each dipole of a nine-element LPV antenna on channel 5. Note that while maximum energy is absorbed by one dipole, No. 5, two other elements, Nos. 4 and 6, absorb 60% as much, and even elements 3 and 7 absorb substantial amounts of signal (30%).

The resonant or near-resonant dipole together with those adjacent elements that contribute substantial signal energy at the received frequency, plus the crossed phasing harness, constitute the "active cell" for that channel. As the frequency of reception increases, the active region moves toward the front of the antenna; for each channel a different active cell is formed.

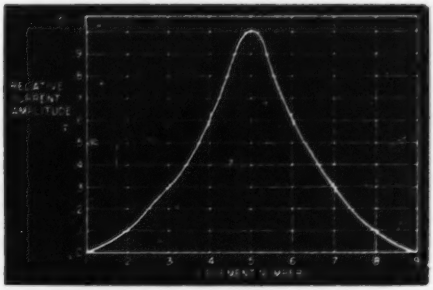


*Fig. 3—Distribution of channel 5 currents on individual elements of a nine-element LPV antenna.*

The tau and sigma used in the design of an LPV are the key in providing a wide active reception region for every channel.[1]When these two factors are selected properly, the dipoles of the active cell present a low impedance at their terminals, resulting in high energy absorption. This low impedance results from a combination of element length and the spacing determined by the log periodic equations, as well as the thickness of the elements.

**High-band operation**

For channels 7 through 13, the large elements at the rear of the antenna constitute 3/2-wavelength dipoles. Therefore, they resonate to the received frequency at the third harmonic mode. The large elements at the rear of the antenna are 3/2 wavelength at channel 7. As the frequency increases toward channel 13, the 3/2 wavelength elements, and therefore the active region, shifts toward the apex of the antenna. The actual gain realized by third-harmonic operation is shown in Fig. 4, the vhf gain curves for the JFD LPV-11, an 11-element antenna. From these curves it is apparent that there is an average increase of 3½ db in gain on the high band vs the low band. This is in accordance with good TV antenna design, which requires greater gain on the high band because of the greater transmission signal losses at these frequencies.

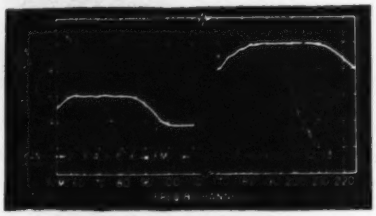
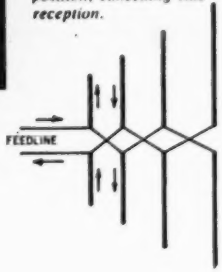


*Fig. 4—Gain curves over TV and FM bands.*

*Fig. 5—Current on adjacent elements is in opposition, cancelling side reception.*




In all other respects, operation is the same as on the low band. Active cells embracing several elements for each channel and low impedance at the received frequency are basic to the antenna.

A close inspection of Fig. 4 shows that the gain of the LPV-11 is uniform across all channels for each band. This guarantees good color TV reception. For color fidelity, the gain on the brightness and color carriers within each channel must be nearly the same. Obviously this can only hold true if the antenna has a flat gain response curve *for the entire channel.*

If the input impedance of an antenna varies appreciably from that of the transmission line at any point in the bandwidth of the antenna, a mismatch will exist between the antenna and downlead. Such as mismatch decreases signal power to the TV set and introduces standing waves along the line. This leads to further signal reduction and ghosts.

The LPV is unique in that it maintains essentially constant impedance across the full bandwidth of the antenna. An important reason for this is that the input impedance of the LPV depends primarily upon the impedance of the feeder network, which can be easily controlled. In the JFD LPV series, the feeder consists of a crossed network of solid bars whose diameter, length and spacing are determined to give an exact match to 300-ohm transmission line. That this is the case is proved by measurements of the vswr which are consistently in the area of 1.2 to 1.

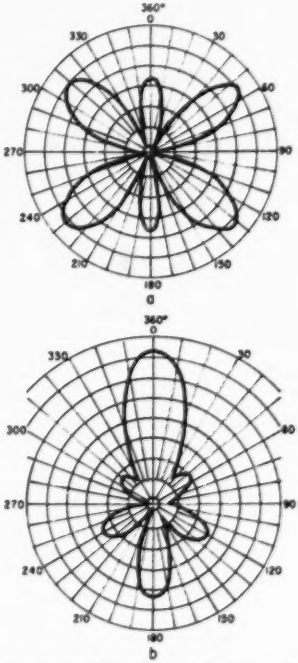



*Fig. 6-a—Polar pattern of half-wave dipole at three times its fundamental. b—Pattern of same dipole with ends bent forward into a shallow V.*

### Directivity, front-to-back ratio

As important as high gain and constant impedance are in fringe-area reception, the antenna would be worthless without good directional sensitivity. Even in the heart of cities, directivity is needed to reject the ghost-causing interference signals that bounce from building to building. In fringe areas, interfering signals from adjacent channels picked up by the antenna from the rear and sides cause venetian-blind and herringbone effects, fading and other picture distortions.

Yagi antennas obtain good directional sensitivity and high front-to-back ratios with parasitic elements (directors and reflectors). The LPV obtains its sharp forward pattern from the V-ing of the elements and the phase-reversed feeder.

Consider Fig. 5, a simplified diagram of a four-cell LPV antenna, front-fed, using a twisted phasing harness. Note that because the elements of the adjacent dipoles are not fed in parallel, they are in phase opposition. This effectively cancels reception from the sides. Furthermore, the length of the harness plus the space between adjacent elements adds up to produce a 360° phase shift between the signals reaching the first and those being picked up by the second element (or between any two adjacent elements) in the forward direction (toward the feedline, at the small end of the antenna). This 360° phase shift actually puts both waves in phase for additive signal strength.

Toward the rear, on the other hand, there is only a single 180° phase shift, due to the crossed harness. This effectively cancels reception from adjacent elements towards the rear.

The signal finds itself in somewhat the position of a motorist going down an avenue that has phased traffic lights. Arriving at the front (small end) of the antenna, it finds each element in turn phased in its favor, and gives up a maximum of its energy to the antenna. If it arrives from the rear, it finds each alternate element phased against it, and is effectively cancelled out.

Directional sensitivity is increased and reception from the rear further reduced by V-ing the elements forward. A straight half-wave dipole receiving a signal three times its resonant frequency has a radiation pattern like that shown in Fig. 6-a. The signal sensitivity is dissipated in three forward lobes. If the elements of this same dipole are directed forward into a V, the pattern becomes Fig. 6-b. The two side lobes are brought together and merged with the center lobe as the elements are brought toward each other. The rearward lobes are "phased out" in the feedline.

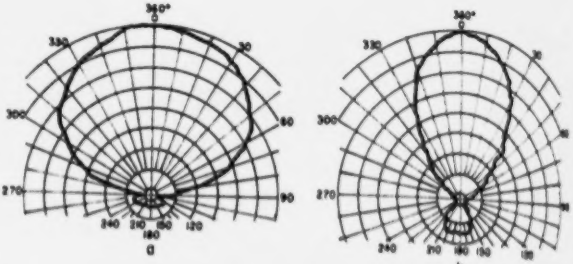



*Fig. 7—a—Polar pattern of LPV on low TV band. b—Same antenna on high band*

Reception patterns for the complete LPV TV antenna are shown in Fig. 7-a for the low band, sharpening up to 7-b on the high band. This type of pattern is maintained through the FM band too. In actual tests the LPV-11 with 9 active cells and 2 directors maintained a front-to-back ratio of 35 db, with a gain of 8 db across the low band and 11½ db across the highs. In comparison, a somewhat longer Yagi antenna, adjusted to a front-to-back ratio of 25 db at the middle of its band, fell to 15 db at the edges, and more important, had a bandwidth of only 7%, at a gain equal to that of the LPV.

Although reflector elements are unnecessary for the LPV, directors are desirable to "peak up" the high end of the upper vhf band, particularly for fringe-area reception. The director spacing is determined experimentally since it must not affect the input impedance of the antenna itself. Laboratory tests recommended a spacing of approximately half the distance between the two shortest active elements of the antenna. Director length is shorter than the shortest active elements—theoretically, it should be 0.46 multiplied by the half-wavelength of the frequency to be "peaked".

### City and far fringe

Since the frequency independence of the LPV depends on the scaling of the cells, any number of intermediate cells may be narrowed without affecting the essential characteristics of the antenna. To narrow an antenna, a smaller value of tau is chosen, so that the shortest element is approached faster, omitting some elements in between. Narrowing the cells will reduce the gain but will not affect the front-to-back ratio, directivity and constant-impedance characteristics, which do not depend on the number of elements used, only on the adherence to the proper scaling factors and equations.

When a shortened LPV is used in a strong-signal area, the increased signal strength will compensate for the fewer total signal-absorbing elements. At the same time, it is no less important that suburban and city viewers use an antenna with high front-to-back ratio and low vswr to eliminate ghosts caused by signal reflection from tall buildings.

There are presently six models in the LPV series made by JFD. The shortest, the LPV-4, contains 4 active cells and is recommended for use up to 50 miles from the TV transmitting antenna; in other words, in city and most suburban areas. The largest is the LPV-17 with 8 active cells and 10 passive elements. This one is designed for use up to 175 miles from the transmitter under virtually ideal conditions. Between these two are four other models for any reception area.

Since element spacing and V-ing are critical, special mechanical innovations were needed to assure antenna rigidity. The crossarm is made of extra-heavy-gage aluminum, 1 inch square. Every element has sleeve reinforcements to prevent bending. The phasing harness is made of ¼-inch solid aluminum rod, cold-welded into position. Other mechanical features are "flip-quick" construction for ease in erection, gold alodizing and the inclusion of a double U-bolt assembly.

A fortunate dividend in the LPV design is its "compatibility" with uhf. When and if combination vhf-uhf antennas find an increasing market, it is almost certain that the LPV will be one of the leading all-band designs. END

SEE THE JFD LOG PERIODIC LPV AT YOUR JFD DISTRIBUTOR NOW—AND BE THE FIRST ONE IN YOUR AREA TO INTRODUCE AND PROFIT FROM THIS NEW ERA IN TV RECEPTION

THE BRAND THAT PUTS YOU IN COMMAND OF THE MARKET

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NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
A-42
GOVERNMENT EX. NO.
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Reprinted from RADIO & TELEVISION NEWS

# JFD Electronics Antenna Laboratory Employs Industry's Hidden Resource

## Forms Alliance With the University of Illinois; New Laboratory Established Under the Direction Of Prof. Paul E. Mayes, an Antenna Authority

By ALBERT FINKEL
President
JFD Electronics Corp.

...for too long, the field of TV an... design has followed narrow ... set down decades ago by early ... This is usually apparent ... the trained eye. Behind many va... is element number and lay... is the familiar yagi.

...designers have displayed much in...

Prof. Paul E. Mayes

...ity to escape the yagi's inherent ... frequency and selectivity, ... adapt it to broad-banded per... But the attempt to widen ... leads to compromise—the ... dilemma in which gain is ... off against bandwidth. Re... curves show it. Peaks and val... prove how elusive the ideal an... can be.

Which route must the commercial ... manufacturer travel? How ... he pin down new concepts that ... to high antenna gain, constant impedance match and good front-to-back ratio distributed smoothly over large regions of the VHF and UHF bands?

The answer, for some, has been to expand an engineering staff and relegate it the task of producing something new. But doesn't the history of antenna design suggest otherwise? With talented engineers and fine facilities, innovations that touch off broad, fundamental change rarely spring from the commercially oriented lab.

### A Fresh Approach

We can only speculate on causes: the pressure to produce practical units ready for market or perhaps the formidable task of designing whole antenna lines based on known principles. Whatever the reason, it is clear that a fresh approach is in order.

It is no secret that many of today's fundamentally new concepts arise from basic research. Consider anything from the talking machine to the transistor, and chances are that original thinking for these valued devices sprang from the creative rambling that characterizes the research lab. For it is here that the engineer is free to abandon the convention of his time and strike out in untried directions.

Few will dispute the number of practical solutions and hardware derived from original thinking done in the research lab. Government and defense-based industry attest to this.

But consider private industry intent on improving products for consumer use. How can it tie into the engineering pipeline at the pure research level—unassisted by outside subsidy or government contract?

JFD Antenna Lab

Must it underwrite the vast expenditure that typifies the research program, or await shake-out from military and space developments that filter down to civilian industry years later? In JFD's search for antenna technology on the breakthrough level, we discovered what may be called a "hidden resource." It is the basic research program of a great university.

### A Hidden Resource

This is not an exploration into the academic world in the usual sense. The alliance is not based on college courses for engineering personnel, attending seminars or surveying technical literature in the field of education. Far more dynamic in its ramifications, it prompted the creation of the JFD Research and Development Lab and a unique relationship with the University of Illinois.

It represents, for the first time, an effort by a TV antenna maker to probe utterly new areas of technology without the limitations imposed by the past.

Establishing the lab was not an overnight feat. It emerged from a sequence of events that drew together the university and JFD during a lengthy, evolutionary process. But first a look at why JFD directed its attention to the academic world at all.

### Engineering Colleges

The engineering colleges have emerged as the hub of today's most advanced and exciting technology. This has long been recognized by the U. S. Government, which has expressed its confidence through sizeable R&D contracts.

This is suggested in the words of a leading educator, Provost Frederick E. Terman of Stanford. He says: "Education is perhaps the most significant factor affecting the future of electronics.

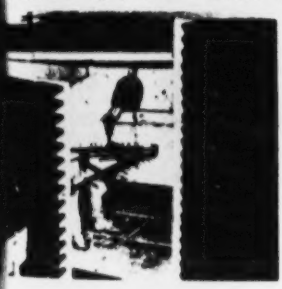
"Universities can provide intellectual leadership — a point of focus." Given these heady ideas, how could JFD translate them into working reality and apply them to the every day problems that yielded to no conventional solution?

### Point of Focus

It's easy to see why our "point of focus" came to rest at the University of Illinois. For years the university's Antenna Research Lab attracted the attention of professional engineering circles and the antenna field in general. It is ranked by many as one of the two top antenna research labs in the country, if not in the world. Impressive work was being done here—the kind of research that promised to upset existing concepts and establish the guide-lines for the much sought-after frequency independent antenna. The implications were enormous.

It is a matter of history now that the University of Illinois' antenna lab, working under Government contract, produced the log-periodic antennas that have significantly pushed forward the state of the art.

Here were techniques that broke the 2-to-1 frequency limits of early wide-band antennas. Indeed, the new designs suggested the theoretical pos-



# JFD Electronics Antenna Laboratory Employs Industry's Hidden Resource

## Forms Alliance With the University of Illinois; New Laboratory Established Under the Direction Of Prof. Paul E. Mayes, an Antenna Authority

(Continued from Page 12)

sibility of 20-to-1 bandwidths with no sacrifice in pattern, gain and impedance. If the log-periodic formulas could be applied to the TV engineer's problems, here would be the long-awaited break-through.

The university was not unaware of the considerable impact its findings might have on commercial antennas. Neither was JFD. After negotiating and winning exclusive rights to produce the log-periodic, JFD set its engineers to the task of producing commercially feasible designs.

After a year of lab and field testing, the LPV line of log-periodic TV antennas appeared on the market. Its unusual engineering fulfilled the early promise of a broad-band TV antenna with performance comparable to that of a 1-channel yagi of similar size.

So well did the cooperative venture with the University of Illinois succeed, that JFD decided to find a method of "priming" comparable breakthroughs in antenna techniques.

The answer materialized in December, 1962 with the opening of the JFD Research and Development Lab. This was no mere appendage to JFD's existing engineering facilities. The new lab was not intended to duplicate something already in existence. Rather, it sought to penetrate the technological wealth proved to exist at the academic level. The lab was situated on the University of Illinois' home ground; the Champaign-Urbana area.

The array of engineering talent now within easy reach was impressive. It was possible to secure the services of Dr. Paul E. Mayes, whose pioneering work as co-inventor of the log-periodic re-inforced his prominence as a distinguished antenna authority.

Named as consultant to the new JFD lab, Dr. Mayes' credentials are outstanding.

The project engineers selected for the JFD antenna lab were Marvin Fastman and Ronald Grant, also prominent in this field.

Under the direction of Dr. Mayes, both are now at work on further commercial developments of the LPV principle.

A significant advantage of situating the JFD lab near the university is reflected in the caliber of its technicians. Comprised of graduate students and seniors in electrical engineering, these men are the equivalent of junior engineers.

The staff is completed by several full-time engineering and management personnel.

As in any lab, continuity of research is a key factor. Thus, the lab's greatest resource—an imaginative and competent research group, headed by a prominent authority—had been welded into a team possible under no other set of circumstances.

The physical plant for the JFD lab is located at Champaign, it is equipped with the modern test apparatus needed for development of antennas in the VHF-UHF portion of the spectrum. It occupies 2,000 square feet of indoor floor space with a flat, elevated roof for outdoor tests. Atop the roof are three towers and rotators. One 71-foot tower supports a mast for mounting up to four antennas side by side during comparison tests. There is a positioner which holds antennas in a reflection-free position for taking such readings as input impedance and VSWR.

For outdoor tests, one or a combination of techniques determines significant characteristics of antenna performance. With an antenna held in a reflection-free position, lecher line, diagraph and slotted line yield information on VSWR and impedance, depending on antenna type.

Indoors, lab facilities are similarly extensive. Here is contained instrumentation for elaborate tests and measurements. There is a complement of woodworking and machine tools that enable the technician to fabricate actual-size or scaled-down antenna models.

The development of an antenna at the lab usually commences with a set of specifications. After study, the engineers decide on a configuration best suited for the application — TV, FM, or a combination type, for example.

A tentative design is drawn up and models are constructed. These will be used for pattern measurements in free space and to determine input impedance. With the lab's ...ment, tests can be ... the frequency range ... MC. If the operating ... tenna falls outside ... factors can be applied ... model within the lab's ...

Next, in actual ... space radiation to circ... el will meet pattern ... cations. If these factors ... tory, impedance measu...

After a series of ... full-scale antenna ... cations, engineering ... pared. Construction ... may follow, or drawings ... JFD's main facilities ... From this point on, the ... type is advanced toward ... stage by the JFD engi... other locations. Follow... test run at the factory ... turned to the lab to ... production units agree ... na's original specifications.

In the interest of ... has even developed ... strument of original ...

Considering the ... its work has already ... tive. The number of ... antennas to merge ... odic formula is surpris... produced six LPV ... cover all existing ... tered in VHF-TV ... generation has appear... search has made possi... tion of the log-periodic ... and specialized area...

One is FM multi... problems in stereo ... well known: deterioration ... path propagation are ... A new LPV, experi... stereo, has the sensitiv... ity needed to combat ...

And the growing ... has similarly commanded ... tention. Six new UHF ... models will soon prove ... flexibility in handling ... nals common to UHF ... is even an indoor LPV ... comparable to that of ... tic.

The lab's future ... it continues to translate ... into practical design, ... sophistication further ... boundary defined by ... art. Judging by the ... mance, we can expect ... University of Illinois ... produce even greater ... in antenna technology ...

Lab Technician at Test Bench on Roof

B-164 11/16/64

224 Illini . Illinois 61803

# UNIVERSITY OF ILLINOIS FOUNDATION

October 14, 1964

Mr. Ed Finkel
JFD Electronics Corporation
15th Avenue at 62nd Street
Brooklyn, New York 11219

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO._____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Dear Ed:

I meant to answer your October 5 letter before this but I wanted to check the statements with both Professors Jordan and Mayes and they have been very much involved in an Electrical Engineering meeting this week which kept me from getting together with them.

I am sending you the combined opinion of Mr. Jordan, Mr. Mayes and Mr. Samuel B. Smith, in which I concur.

Page 1 of your letter, paragraph 1 is satisfactory.

We ask that you eliminate paragraph 2. I think it can be rephrased but Mr. Jordan objects to it because it indicates that the entire research program was designed for the benefit of JFD. Why don't you try this one over again?

Paragraph 3. Would you please change it to read, "Adapted from research results of the Antenna Laboratory of the University of Illinois."

Paragraph 4. This is troublesome because of the use of the word "patented" and Mr. Smith tells me there are legal reasons why this should not be used.

Paragraph 5. We should like you to change it to read, "LPV -- is designed from the Antenna Research Laboratory of the University of Illinois." The reason we suggest this is that, originally worded, it implies that the Foundation is in the manufacturing business.

Page 2, paragraph 1. We should like to have it changed to read, "The first TV/FM antenna based on the geometrically-derived Logarithmic-Periodic scale developed by the Antenna Research Laboratories of the University of Illinois and used in satellite telemetry."

Paragraph 2. We ask you not to use this one. It is good advertising copy. I think it could be rewritten and modified.

Paragraph 3 is satisfactory.

Paragraph 4 is untrue. The Log-Periodic LPV formula is patented. Patents are issued only on the structure which was based upon principle covered by the formula. This paragraph seems objectionable from legal standpoint. Why don't you rewrite it and resubmit?

Paragraph 5 is satisfactory.

Paragraph 6. We should like to have rewritten as follows: "Significant New Principles Developed by the University. . . . .etc."

Paragraph 7 is not true. It wasn't the University which conceived the idea but the people in the Antenna Laboratory. You may want to resubmit a paragraph similar to this.

Page 3. The paragraph on this page is satisfactory.

Best regards!

Cordially yours,

James C. Colvin
Executive Direct

JCC:pw

cc: Mr. Samuel B. Smith

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO.
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

B-105
11/1/66 FI

April 21, 1964

Morriam, Smith & Marshall
30 West Monroe Street
Chicago, Illinois

Attention: Mr. Sam Smith

Re: University of Illinois
and LPV

Dear Sam:

In reply to yours of April 15th, I enclose two additional copies of the pamphlets requested. There are other pieces in work which are at the printers right now. As soon as they are available I will send them on to you.

In reading your letter, I am a little concerned about your reference to Paragraph 2 of the agreement, referring to patents. If you recall, at the beginning we had not used the patent phrase properly and it was on your instructions that I changed the phrase to read, "Licensed under one or more of U. S. Patents 2,950,081; 2,935,079; 3,011,169; 3,109,200 and additional patents pending in U.S.A. and Canada. Produced by JFD Electronics Corporation under exclusive license from the University of Illinois Foundation."

You explained that it was not necessary that each and every patent be applicable to the specific product on which this phrase was printed, but so long as it referred to one of the patents, it was permissible.

Mr. Sam Smith (Cont.)

At the present time we are not selling any products that come under the Dyson, DuHamel and Isbell patents. However, in the very near future, we intend offering a log periodic Trapezoid indoor antenna which Paul feels comes under the Isbell patent.

I trust this is the information you desired.

Kindest regards.

Sincerely,

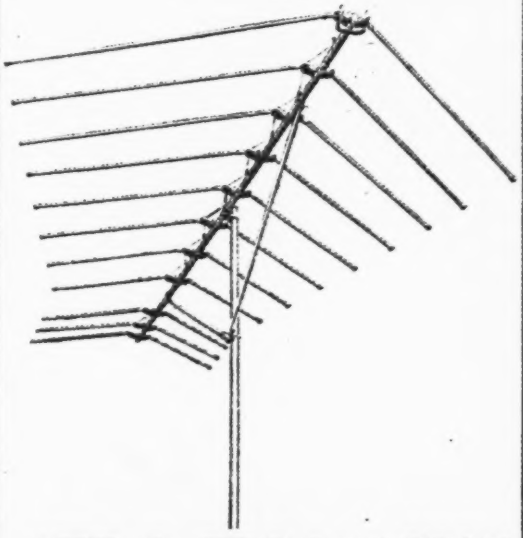
Ed Finkel

EF/ss
cc- P. Mayes
J. Colvin
S. Faber

**LPV** ...from the Antenna Research Laboratories of the University of Illinois

**LPV** ...from the satellite tracking techniques of the U. S. Air Force

**LPV** ...a remarkable new space antenna formula now adapted by JFD for sharper and clearer reception in glowing COLOR or vivid Black and White TV — plus FM Stereo!



# JFD LPV LOG-PERIODIC TV/FM ANTENNA

*U.S. PATENTS 3,008,081-3,095,579-3,211,199—Additional Patents Pending

$$\frac{L_{(n+1)}}{L_n} = \tau$$

The log-periodic antenna, as represented by this formula, was invented by the Antenna Research Laboratories of the University of Illinois. Using this basic log-periodic formula, JFD Electronics has developed the log-periodic LPV TV/FM antenna that works wonders in reception. Snowy, faded pictures suddenly come aglow with radiant detail . . . "ghosts" and interference vanish . . . shows from distant stations come in crisp and steady. And if you like FM Stereo you can hear it at its best with the same log-periodic LPV TV/FM antenna.

**NO LAZY ELEMENTS**—ENTIRE ANTENNA RESPONDS TO SELECTED CHANNEL. All antenna elements (not just some elements as in other antennas) respond to the channel you want—absorb maximum signal on every channel from 2 to 13, as well as on all FM Stereo frequencies. And the JFD log-periodic LPV is ruggedly built—wind-tested to 100 m.p.h. winds. Lustrous gold alodized aircraft aluminum keeps it looking and working like new. PRICED FROM $14.95 to $59.95

**See your TV Dealer or Mail Coupon Now!**

**LOG-PERIODIC JFD LPV TV/FM ANTENNA**

JFD Electronics Corporation, 1462-62nd St., Brklyn, 19, N. Y.
Please send me JFD report on log-periodic antenna.

NAME.....

ADDRESS.....

CITY.....STATE.....

B-107
11/16/64 H

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

DEFENDANT EX. NO._____
DOROTHY L. BRICKENBURY
OFFICIAL COURT REPORTER

**IN STOCK**

ADVERTISED IN LOOK

Form No. 571 (Rev-8)

no guess-work about it—

the JFD LPV $\frac{L_{(n+1)}}{L_n}=\tau$ IS A WINNER

"6 db BETTER THAN THE BEST!"

If you are installing JFD Log Periodic LPV's, no doubt you will agree with this report from R. L. Monroe, a leading TV antenna service-dealer of Charleston, West Virginia—a problem reception area.

*"It beats all, it beats everything that I have ever seen. Not only that, but this antenna is better than 6 db better than the best that I have installed. It pulled in a consistently clear picture from Columbus, over 130 miles away. ••• ••• ••• • "It's just great on color—turns browns into real reds, faded bluish greens into brilliant greens, and completely eliminates the chronic ghost problems we have been suffering from in this area."*

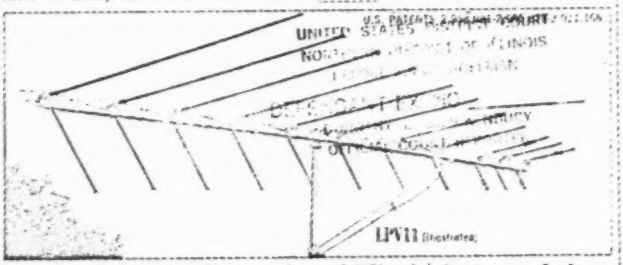
*"I have been in this business since 1948, which is a considerable time, particularly in the valley, and have yet to see any antenna, even near to this log periodic antenna in performance of the things I have wanted."*

Periodic LPV!

Outperforms Every TV Antenna Ever Made!

The log periodic LPV blows the window on conventional antennas with their "Chinese puzzle" combinations of collectors, directors and reflectors. Now a single precisely engineered antenna—the first based on a geometrically-derived *logarithmic* scale—actually *tunes* itself to the desired channel for unprecedented performance in crisp black and white or stunning color—plus FM STEREO. Is it any wonder that never before have so many installers and technicians so quickly acclaimed a TV antenna?

We would like to tell you more about the LPV, and how its *frequency independent* characteristics have driven through distance, fixed and interference barriers to bring clear, steady pictures into previously "impossible" areas. Write today for your log periodic LPV Sales Kit. Better yet, call your JFD distributor and try one with our money back guarantee of a better picture. You will prove it to yourself.




**Developed by the University of Illinois Antenna Laboratory—Now Serving in Satellite Telemetry—Adopted to TV by JFD! THE LOG PERIODIC LPV ENDS THE ERA OF ANTENNA COMPROMISE! FOR THE FIRST TIME ONE SCIENTIFICALLY FORMULATED ANTENNA CONFIGURATION SATISFIES ANY LOCATION DEMAND:**

**Harmonically resonant V-element operate on the Log-Periodic Cellular Principle in the Fundamental and Third Harmonic Modes for unprecedented performance—in color—in black and white—plus FM STEREO**

| | | |
|---|---|---|
| LPV17: | 18 Active Cell and Director System—up to 175 miles | $59.95, list |
| LPV14: | 15 Active Cell and Director System—up to 150 miles | $49.95, list |
| LPV11: | 11 Active Cell and Director System—up to 125 miles | $39.95, list |
| LPV8: | 7 Active Cell and Director System—up to 100 miles | $29.95, list |
| LPV6: | 6 Active Cell System—up to 75 miles | $21.95, list |
| LPV4: | 4 Active Cell System—up to 50 miles | $14.95, list |

JFD ELECTRONICS CORPORATION

15th Avenue at 62nd Street, Brooklyn 19, N.Y.
JFD Electronics-Southern Inc., Oxford, North Carolina
JFD International, 15 Moore Street, New York, N.Y.
JFD Canada, Ltd., 51 McCormack Street, Toronto, Ontario, Canada
401-144 W. Hastings Street, Vancouver 3, B.C.

F-109 White II

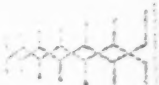
UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

DEFENDANT EX. NO._____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER


of the University of Illinois ... Proved in Space Satellite Tests

## HOW THE LOG-PERIODIC LPV MAKES ALL OTHER ANTENNAS OBSOLETE

The JFD LPV antenna is a direct descendant out of the logarithmic conical spiral antenna used on the Transit satellite. This basic design is FREQUENCY INDEPENDENT—it works like a conical waveguide to yield almost constant gain, matched impedance and a unidirectional polar pattern across an extremely wide band of frequencies.



Dipole version of spiral antenna has elements whose length and spacing is determined by formula derived from conical spiral geometry, so that antenna acts like a spiral with parts of coils missing. A logarithmic scaling multiplier ties the dipoles together into active multi-element cells for each frequency. Crossed phasing harness inserts a 180 degree phase shift between dipoles that cancels signals from rear, reinforces signals from front.

JFD's LPV antenna for TV and FM goes one step further—increases gain and front-to-back ratio while maintaining frequency independence. Forward V-ing of elements shrinks rear radiation lobes, narrows forward beam for sharp directivity, helping to eliminate ghosts and adjacent channel interference. Forward V also permits low band dipoles to contribute to high band gain by operating on the third harmonic mode.

For example, Operation of the JFD LPV-11 on the low band: The largest dipole cells resonate to the low band TV frequencies at their fundamental wavelength. Within each cell, one dipole absorbs the greatest amount of signal for any particular channel, adjacent dipoles pull in 60% more and the next two dipoles add 30% more signal. Many active dipoles working on each channel with constant impedance guarantee high gain.

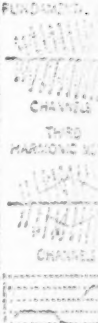
— — — indicates current distribution on fundamental mode.

On the high band. The third harmonic cell forms at the rear of antenna for channel 7 and as the frequency increases toward channel 13, the active region moves toward the apex of the antenna. It is this third harmonic operation which guarantees as much as 3½ db. additional gain. Continuous and co-linear directors sharpen forward pattern and give peak performance across the entire VHF TV band.

— — — indicates the current distribution for the third harmonic mode which will be received on all elements.

. . . . . indicates the active region for channel 10, i.e., the difference with which the elements of the LPV-11 act on channel 10.

The actual gain curves measured for the LPV-11 in the JFD Antenna Research Laboratories confirm this fact. Within the band for which it is designed (the principle will also be adapted for UHF and other uses), the log-periodic LPV's impedance, polar patterns and front-to-back ratio are virtually constant—with gain for each channel as high as that furnished by a comparable-sized single-channel Yagi.




Each antenna in the LPV series consists of an array of resonant V-dipoles and crossed phasing bars, constituting a group of "cells." The size of each cell differs from the one before it by a constant factor. For any particular frequency, the active portion of the antenna centers on the resonant dipole equal to one-half wavelength at that frequency, with the adjacent cells also absorbing significant signal energy. The resonances of adjacent cells overlap, so that as the frequency increases or decreases, it is transferred smoothly from one cell to the next.

In effect, the signal is passed along as the frequency increases—the active area moving toward the apex or small end—until, as the fundamental harmonic reaches cell end, the same progresses resonance in the third harmonic. Conventional wide-band antennas are like rows of compartments, one for each channel desired, with sharp cutoffs. The log periodic antenna is like a continuously moving belt that accepts smoothly any frequency that hops aboard.

SEE THE JFD LOG-PERIODIC LPV AT YOUR JFD DISTRIBUTOR NOW—AND BE THE FIRST ONE IN YOUR AREA TO INTRODUCE AND PROFIT FROM THIS NEW ERA IN TV RECEPTION

*THE BRAND THAT PUTS YOU IN COMMAND OF THE MARKET*

JFD

**JFD ELECTRONICS CORPORATION**
15th Avenue at 62nd Street, Brooklyn 19, N.Y.

JFD Electronics-Southern Inc., Oxford, North Carolina
JFD International, 15 Moore Street, New York, N.Y.
JFD Canada, Ltd., 51 McCormack Street, Toronto, Ontario, Canada

## ('it ended the day JFD introduced the Log-Periodic LPV $\frac{L_{(n+1)}}{L_n} = \tau$ TV antenna)

Wave goodbye to all the Rube Goldberg contraptions with their "Chinese puzzle" combinations of collectors, directors, reflectors.

Now you can solve any reception problem with one compact, precisely-engineered antenna—the first TV antenna based on the geometrically-derived logarithmic-periodic scale developed by the Antenna Research Laboratories of the University of Illinois for the U.S. Air Force.

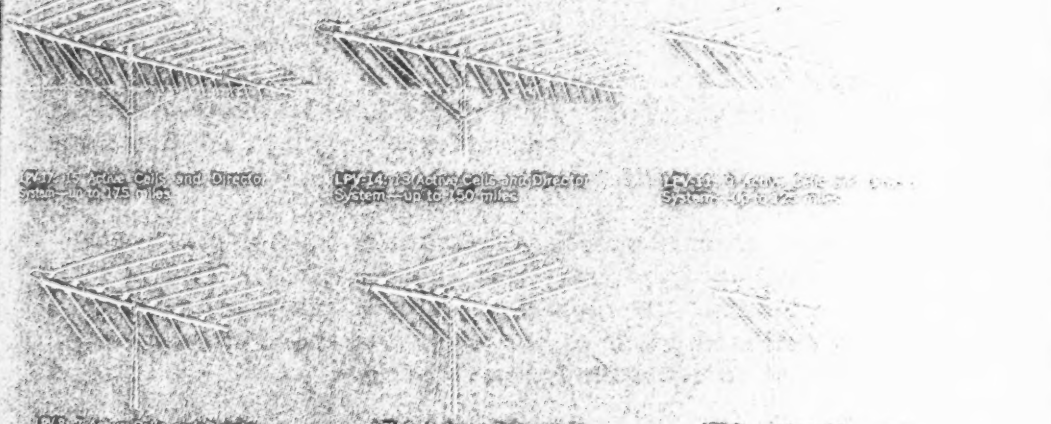
Because it is inherently frequency-independent, the JFD Log-Periodic LPV delivers the same superb performance on every VHF channel—performance comparable to that of a single channel Yagi. And delivers it not only in black-and-white, but in Color, and you get FM stereo too!

THE LOG-PERIODIC LPV ACTUALLY TUNES ITSELF TO EACH RECEIVED FREQUENCY—RESULTING IN:

- HIGHEST GAIN—as high as 14 db. in the LPV 17!
- SHARPEST DIRECTIVITY—on high bands as well as low!
- HIGHEST FRONT-TO-BACK RATIO—up to 35 db.
- LOWEST VSWR—as low as 1.2 to 1—with constant impedance across the full bandwidth!
- FLAT RESPONSE ACROSS BOTH VHF BANDS—with greater gain on the high band, where it's needed most (average increase of gain in high band over low band: 3¼ db.)!
- BROADEST BANDWIDTH—thanks to its unique frequency-independent characteristics!

FOR THE FIRST TIME ONE SCIENTIFICALLY FORMULATED ANTENNA CONFIGURATION SATISFIES ANY LOCATION DEMAND:
Harmonically resonant V-elements operate on the Log-Periodic Cellular Principle in the Fundamental and Third Harmonic Modes for unprecedented performance —in color—in black and white—in FM STEREO

developed by the Famous Antenna Research Laboratories




Adapted to TV and FM Stereo by JFD

✓ ELIMINATES THE NEED FOR AREA-DESIGNED ANTENNAS
✓ 100% PREASSEMBLED "FLIP-QUIK" ASSEMBLY
✓ MASSIVE TANK TURRET BRACKETS THAT DOUBLE-LOCK ELEMENTS
✓ AAA† GOLD BOND ALODIZED TO KEEP THAT BRAND NEW LOOK
✓ EXTRA-RUGGED, DOUBLE-REINFORCED IN EVERY DETAIL
✓ LIGHTEST IN WEIGHT PER DB GAIN
✓ WIND-TUNNEL TESTED CONSTRUCTION

†Attractive, Anti-corrosive Armor

B-111

11/2/66 ff

April 21, 1964

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. _____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Merriam, Smith & Marshall
30 West Monroe Street
Chicago, Illinois

Attention: Mr. Sam Smith

Re: License Agreement Between
University of Illinois Foundation
and JFD Electronics Corporation

Dear Sam:

I had occasion to talk to Sid Faber on some legal matter on April 16th, at which time I mentioned to him having received your letter of April 16th, reviewing the meeting [redacted] had with the people at the University and the Foundation.

As my patent counsel, I sent him a copy of your letter and my accompanying view, copy enclosed, for his comments. He wrote me on April 20th, copy of which is enclosed. It is at his suggestion that I am enclosing all this information for your review.

It seems to me his points are well taken and are very much in accord with my own feelings about this whole matter. In essence, the Foundation is in business as a licensing organization to develop as much income for the University as possible. To foster that end the Foundation and the University must be prepared to support their licensee against tactics of the likes of [redacted]

Mr. Sam Smith (Cont.)

It also seems to me that while you are emphasizing the need of our conforming to Paragraph 10, you are neglecting the responsibilities of a licensor to a licensee, as well as our mutual benefit in establishing a stronger position in the antenna market to sell all LPV antennas.

Sincerely,

Ed Finkel

EF/es
encl.
cc-P. Mayes
J. Colvin

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION
JUDGE HOFFMAN

PLAINTIFF EX. NO. _____

[illegible] BRACKENBURY
OFFICIAL COURT REPORTER

CHARLES J. MERRIAM
SAMUEL B. SMITH
JEROME G. KLOSE
NORMAN M. SHAPIRO
WILLIAM A. MARSHALL
BASIL P. MANN
CLYDE V. ERWIN, JR.
ALVIN D. SHULMAN
R. JONATHAN PETERS
ALLEN H. GERSTEIN
OWEN J. MURRAY
EDWARD M. O'TOOLE
DONALD E. EGAN

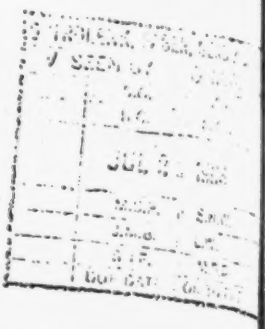
ADMITTED TO D. C. BARS

LAW OFFICES
MERRIAM, SMITH & MARSHALL
THIRTY WEST MONROE STREET
CHICAGO, ILLINOIS 60603

TELEPHONE
FINANCIAL 6-5757

July 17, 1964

UNIV - ILL
FOUNDATION



Mr. Ed Finkel, Vice President-Sales
JFD Electronics Corporation
1462 Sixty Second Street
Brooklyn, New York 11219

Re: JFD "Log-A-Lad" Antenna

Dear Ed:

It is practically at the close of business today and I have just had the opportunity to look quickly at some of the promotions you sent me with your July 15 letter. Immediately my attention was directed to this type of antenna and the prominently displayed statement "brings the acknowledged Log-Periodic design of the Antenna Research Laboratories of the University of Illinois to a new peak of performance!"

This material was never submitted to the Foundation nor to this office prior to its publication. It just happens that I was able today to see Mr. Colvin, and just a moment or two before dictating this letter. I am directed to state that this is not the type of publicity that can be approved by the Foundation or the University, and you have not complied with the provisions of paragraph 10 of the license. I can assure that if this policy and action on your part continues, the Foundation will cancel your license forthwith. This type of publicity does not appear to be anything except to use the University really as a gimmick, which cannot be sanctioned.

Sincerely,

Samuel B. Smith

SBS:mn

cc: Mr. James C. Colvin
Mr. Sidney G. Faber

# All-New JFD Log-Periodic® Antennas for the finest color and black/white TV pictures on channels 2 to 83.

* the Log Periodic is a totally new and different antenna adapted by JFD from the famous satellite tracking antenna design of the Antenna Research Laboratories of the University of Illinois

Wherever you live...whichever channels you want...JFD has the LPV Log-Periodic antenna you need for clearer, sharper pictures in glowing COLOR—or black and white.

JFD LPV Log-Periodics are more powerful because all its elements (not just some elements, as in other antennas) work on the channels you want.

Check below for the JFD Log-Periodic especially engineered for the channels you want.

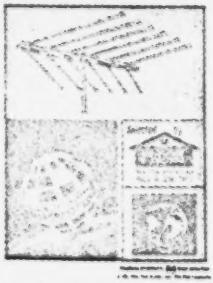
## FOR "PROBLEM" CHANNEL 14 TO 83 AREAS

**Where stations are not near each other—JFD UHF ZIG-A-LOG LOG PERIODIC TV ANTENNAS.**

The new Zig-a-Log is based on one of science's newest approaches to microwave antenna design—the **vertically polarized Log-Periodic planar helical.**

As a result, the Zig-a-Log pulls in sharp pictures in weak signal areas ... eliminates the need for a rotator in UHF areas where stations are located apart from each other.

***AND FOR THE BEST CHANNEL 2 TO 13 PICTURE IN SIGHT—COLOR, OR BLACK & WHITE—REPLACE YOUR OLD OBSOLETE VHF ANTENNA WITH THE—***



LOG PERIODIC

# JFD VHF LPV

Developed from research performed at the University of Illinois Antenna Research Laboratories, and adapted for TV by JFD—the **VHF** Log Periodic LPV brings you the best possible reception on channels 2 to 13, plus FM. The secret of its power is its patented design—the same as that used in antennas to track satellites through space.

Six VHF LPV Log Periodics to choose from—suit any location needs.

| model | range | list |
|---|---|---|
| LPV4 | up to 50 miles | $14.95 |
| LPV6 | up to 75 miles | 21.95 |
| LPV8 | up to 100 miles | 29.95 |
| LPV11 | up to 125 miles | 39.95 |
| LPV14 | up to 150 miles | 49.95 |
| LPV17 | up to 175 miles | 59.95 |

Form No. 730 Litho in U.S.A. 4/61

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
JUDGE HOFFMAN

PLAINTIFF - EX. NO.

## Rely on JFD accessories from antenna to TV set!...

**UHF CONVERTER** — Advanced all-transistor circuitry for highest reliability . . . finest performance. Exclusively illuminated station rule fine tuning. Beautiful "slim-line" styling.

| model | description | net |
|---|---|---|
| CN2-3 | 2-Transistor and Diode | $39.95 |
| CN1-1 | 1-Transistor and Diode | 29.95 |

**TELE-AMP ANTENNA AMPLIFIER** — Strengthens any signal, clears up snow and interference. Completely transistorized. Mounts on any antenna crossarm. Feeds one or two sets.

### SELECT A TELE-AMP MODEL TO FIT YOUR EXACT NEEDS

**Tele-Amp Model VUT-3, 3-Transistor VHF/UHF TV — B/W & COLOR plus . . . F/M Stereo** List Price $49.95
Especially designed as companion to new JFD Model LPV-VII Antenna for a single system to deliver unprecedented power on all TV channels plus FM and FM Stereo.

**Tele-Amp Model VN-2, 2-Nuvistor VHF TV, B/W & COLOR** List Price $39.95
Especially designed for metropolitan use to prevent strong local signals from ruining reception on desired channels. Shows true picture improvement where old fashioned pre-amps fail.

**Tele-Amp Model VT-2, 2-Transistor** List Price $39.95
Two stages provide highest amplification. All solid-state reliability outlasts all other designs. Preferred by suburban TV viewers where there are only medium-strong local stations.

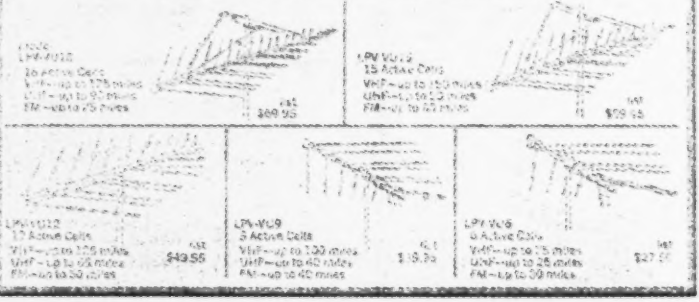
**Tele-Amp Model VT-1, 1-Transistor VHF TV, B/W & COLOR Plus F/M Stereo** List Price $34.95
Preferred by suburban fringe area TV viewers. Not recommended for use in strong signal areas.

**Tele-Amp Model UHT-1, 1-Transistor UHF TV, B/W & COLOR** List Price $39.95
Clears up and brightens UHF stations. Solid-state reliability for years of trouble-free service.

**Tele-Amp Model FT-1, 1-Transistor FM & FM Stereo** List Price $34.95
Assures reception of 90% of all FM stations within 200 miles. Ideal for Stereo-multiplex. All solid-state design requires no servicing, lasts for years.

## IF YOU LIVE IN AN ALL-CHANNEL (2-83) VHF/UHF/FM STEREO LOCATION,

— instal the new JFD CAP ELECTRONIC DIPOLE LOG PERIODIC.



## *Now - space age antenna science brings you amazing TV reception!*

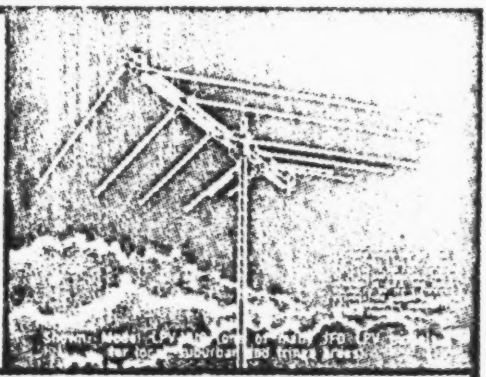
1965

# Don't be 1/2 set

***BE ALL SET!***

***Enjoy All Channels 2 to 83 (FM, Too)***

## JFD LPV® LOG-PERIODIC TV/FM ANTENNA



**The JFD LPV Log Periodic Helps Your TV Get Sharp, Brilliant Pictures—COLOR & Black/White**

$$\frac{L_{(n+1)}}{L_n} = \tau$$

The LPV follows the new **log periodic** formula developed for space telemetry by the famous Antenna Research Laboratories of the University of Illinois. The LPV also features new **capacitor-coupled** diodes that work **electronically** for full picture power on all 82 VHF & UHF channels. No other antenna employs this revolutionary new patented TV antenna design.

Own a new UHF/VHF 82-channel TV receiver? Converting your present TV for 82-channel performance? Don't be ½ set — be all set to receive all channels 2 to 83, in brilliant **COLOR**, and black and white plus FM stereo. Install the **new** TV antenna discovery, the JFD LPV Log Periodic and watch your picture come alive with crisp detail, rich contrast — not on some channels but all channels — near and far. The reason? All antenna elements (not just some as in other antennas) respond for **maximum** picture on **every** channel — because of the JFD LPV's space-age **log periodic** design. SEE YOUR LOCAL JFD LPV DEALER TODAY!

World's largest manufacturer of TV & FM antennas

**JFD ELECTRONICS CORPORATION**

14-02A · 62 Street, Brooklyn, N. Y. 11219

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

PLAINTIFF EX NO.
DEFENDANT
OFFICIAL COURT REPORTER

J-6

→ 15B J-20 11/2/66

UP Inc.
UNIVERSITY PATENTS, INC.
Thirty West Monroe Street, Chicago, Illinois 60603
Code 312-332-6505

JUL 2[illegible] 1966

July 25, 1966

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO.
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Mr. Ben H. Tongue
Blonder-Tongue Laboratories, Inc.
9 Alling Street
Newark, New Jersey

Dear Mr. Tongue:

Subject: University of Illinois Log Periodic Antenna Patents.

I am sorry that I have been unable to reach you by phone during the past two weeks. The purpose of my calls has been to confirm the information that I believe you may already have concerning the availability of licenses under the University of Illinois Foundation antenna patents and patent applications.

Our exclusive agreement with our licensee is limited specifically to the field of receiving antennas for television and frequency modulation (FM) broadcasting stations and antennas for amateur and citizen's band transmission and reception. Our licensee has the right to and has agreed to sublicense within this field and would be happy to discuss terms and conditions for such sublicense. In all other fields, non-exclusive licenses can be obtained directly from us. We would also be happy to discuss terms with you in this connection. In order that you may have ready access to the specific patents that have issued, I have enclosed a schedule of these issued patents. The various patent applications can be discussed in connection with a discussion of terms.

University Patents, Inc. is an affiliate of the University of Illinois Foundation and is charged with the responsibility of handling all of the University's patent assets and programs.

Very truly yours,

Emil W. Wickert

Emil W. Wickert
Vice President

EWW/bem
Enclosure

JUL 27 1966

## EXHIBIT A - ISSUED PATENTS

| Inventor(s) | Patent No. | Issued | Title |
|---|---|---|---|
| Dyson | 2,958,081 | 10-25-60 | Unidirectional Broadband Antenna Comprising Modified Balanced Equiangular Spiral |
| DuHamel | 2,985,879 | 5-23-61 | Frequency Independent Antennas |
| Isbell | 3,011,168 | 11-28-61 | Frequency Independent Unidirectional Antennas |
| Mayes & Carrel | 3,108,280 | 10-22-63 | Log Periodic Backward Wave Antenna Array |
| Carrel & Mayes | 3,150,376 | 9-22-64 | Multi-Band Log Periodic Antenna |
| Mayes & Carrel | Re 25,740 | 3-9-65 | Log Periodic Backward Wave Antenna Array |
| Dyson & Mayes | 3,188,643 | 6-8-65 | Circularly Polarized Omnidirectional Cone Mounted Spiral Antenna |
| Isbell | 3,210,767 | 10-5-65 | Frequency Independent Unidirectional Antennas |

(13)

SERVICE

WHOLESALE
TELEVISION AND RADIO
SUPPLIES; WEBCOR STEREO,
FONOS, TAPE RECORDERS.

SACRAMENTO ELECTRONICS
SUPPLY CO.

1219 S Street GI lbert 1-4821
SACRAMENTO 6, CALIFORNIA

May 18, 1966

to Mr. Gilbert

RECEIVED
MAY 23 1966
B-T LABS
MARKETING
DEPT.

Mr. Dick Heinoski
Blonder Tongue Labs, Inc.
9 Alling Street
Newark, New Jersey 07102

Dear Dick:

Per our telephone conversation regarding antennas, I have enclosed copies of the information that we received from JFD.

See you at the show!

Yours truly,

SACRAMENTO ELECTRONIC SUPPLY CO.

C. E. Bohmbach

C. E. Bohmbach, Jr. (Skip)
Manager

Encls.

cc: Rines & Rines
10 Post Office Square
Boston, Mass.

61

FILED
AUG 27 1968
AT ____ O'CLOCK
ELBERT A. WAGNER, JR.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN
DEFENDANT EX. NO. 43
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

TO: ALL JFD DISTRIBUTORS April 19, 1966

FROM: ED FINNEY

SUBJECT: UNIVERSITY OF ILLINOIS FOUNDATION SUES:

BLONDER-TONGUE LABORATORIES, INC.

CHANNEL MASTER CORPORATION

JERROLD ELECTRONICS CORP.

FOR LOG PERIODIC ANTENNA BASIC PATENT INFRINGEMENT

The above firms now join Finney Company and Winegard Company in the list of manufacturers being sued by the University of Illinois Foundation for patent violations.

A reprint of the official press release, and the article from Home Furnishings Daily of April 18, 1966, specify the actions taken against the patent violators.

The Foundation is taking vigorous action in the courts to sue all violators of the basic Log Periodic Patents. JFD is the EXCLUSIVE licensee of the Foundation authorized to manufacture antennas under these basic patents.

If emulation is the sincerest form of flattery, then JFD and its Franchised Distributors must be selling the finest TV and FM antennas on the market today. The fantastic acceptance and success of the whole JFD LPV antenna line attests to the validity of this conclusion.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

62

DEFENDANT EX. NO._____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

HOME FURNISHINGS DAILY, MONDAY, APRIL 18, 1965

# Antenna Patent Suit Hits Jerrold

CHICAGO. — The University of Illinois Foundation, Urbana, charged in Federal Court that Jerrold Electronics Corp., Philadelphia, and R. Cooper, Jr., Inc., here, make or cause manufacture and sale of radio and TV antennas that infringe two of its patents.

The patents are Nos. 3,150,376, for a multiband, log-periodic antenna, and 3,210,767, for a frequency-independent, unidirectional antenna.

The suit asks for injunctions and an accounting and award of damages.

Merriam, Marshall, Shapiro & Klose represents the foundation.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

DEFENDANT EX. NO. _____

DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

63

224 Illini Union · Urbana, Illinois 61

UNIVERSITY OF ILLINOIS FOUNDATION

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE HOFFMAN

April 7, 1966

DEFENDANT EX. NO._____
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

Hjalmar W. Johnson, President of the University of Illinois Foundation, revealed today that the Foundation had filed civil actions in the Federal District Court in Chicago against Blonder-Tongue Laboratories, Inc., Allied Radio Corporation, Channel Master Corporation, and Electronic Distributors, Inc., charging infringement of one of the Foundation's Log Periodic Antenna patents.

Mr. Johnson stated that the Log Periodic Antenna Inventions constitute one of the most important new developments in the antenna industry and that the Foundation Antenna licensing programs is one of the most important income sources for the Foundation.

Earlier this year the Foundation filed a civil action in the Federal District Court of Iowa against the Winegard Company, charging infringement.

The JFD Electronics Corporation of Brooklyn, New York, has an exclusive license under the patents in the field of receiving antennas for television and FM broadcasting stations, and antennas for amateur and citizens band transmission and reception. All other fields are licensed non-exclusively by the Foundation.

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## LICENSE AGREEMENT

THIS LICENSE AGREEMENT entered into this 31st day of May, 1962, by and between the UNIVERSITY OF ILLINOIS FOUNDATION, a non-profit corporation organized and existing under and by virtue of the laws of the State of Illinois, hereinafter referred to as "LICENSOR," and JFD ELECTRONICS CORPORATION, a corporation organized and existing under and by virtue of the laws of the State of New York, hereinafter referred to as "LICENSEE."

WITNESSETH:

WHEREAS, LICENSOR is the owner of the entire right, title and interest in and to Letters Patent of the United States as follows:

2,958,081, dated October 25, 1960 - J. D. Dyson - entitled "Unidirectional Broadband Antennas,"

2,985,879, dated May 23, 1961 - R. H. DuHamel - entitled "Frequency Independent Antennas,"

3,011,168, dated November 28, 1961 - D. E. Isbell - entitled "Frequency Independent Unidirectional Antennas,"

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CLERK

as well as U. S. applications for Letters Patent of the United States, Serial No. 26,589, filed May 3, 1960 by D. E. Isbell entitled "Frequency Independent Unidirectional Antennas," Serial No. 59,671, filed September 30, 1960 by P. E. Mayes and R. L. Carrel entitled "Frequency Inde-

pendent Unidirectional Antennas," Serial No. 79,432, filed December 29, 1960 by J. D. Dyson and P. E. Mayes entitled "Circularly Polarized Omnidirectional Antenna." and Serial No.

as well as the invention set forth and described in and by each of the aforesaid Letters Patent of the United States and applications for Letters Patent of the United States; and

WHEREAS, LICENSOR holds the sole right to grant the license right herein granted and agreed to be granted; and

WHEREAS, LICENSEE is desirous of securing, for the term of years hereinafter set forth, an exclusive license to manufacture, use or sell, or to have made for its use or sale, apparatus of the type described and claimed in and by each of the aforesaid Letters Patent of the United States and applications for Letters Patent of the United States as the same is therein disclosed and set forth.

NOW, THEREFORE, in consideration of the foregoing and the mutual terms and conditions of this License Agreement and other good and valuable consideration, the receipt and sufficiency of all of which is hereby duly acknowledged, the parties hereto agree as follows:

1. LICENSOR hereby grants and agrees to grant to LICENSEE an exclusive non-transferable right and license in the United States to make, use or sell or have made for its use or sale any invention described in any of the afore-

mentioned Letters Patent as well as the aforesaid applications for Letters Patent, the components so manufactured, used or sold being referred to hereafter as "Licensed Articles." Said exclusive license shall extend for the term of from the date of allowance of one or more claims in either application Serial No. or Serial No. which cover and define LICENSEE's manufactured Licensed Articles. Thereafter, LICENSOR shall have the right to grant other licenses in the Licensed Articles, but in such event shall give at least ninety (90) days' notice thereof to LICENSEE, and LICENSEE's royalties, hereinafter provided, shall be no

Royalties

herein provided shall hereafter not be in effect. The license granted hereunder shall extend also to any continuation, division, or continuation-in-part of any of said applications for Letters Patent and to any reissues of any of the licensed patents.

2. All Licensed Articles manufactured and sold by LICENSEE under the terms of this License Agreement shall carry such reasonable notice as LICENSOR shall from time to time request in writing and which shall comply with the provisions of Title 35 United States Code, Section 287.

3. LICENSEE agrees to make the following payments to LICENSOR:

Page Five

The precentage royalty rate shall be computed upon the net selling price of such Licensed Articles made, used or sold by LICENSEE or made by others for its use or sale. Such royalty, however, shall be payable only upon sale of the article except in those cases in which the article is consumed by or for LICENSEE without sale. In such cases, royalties shall be computed at the normal selling price of the device. Licensed Articles made during the life of a licensed patent covering the same, but not sold until the expiration of said patent, shall be subject to royalty. In the event of cancellation of this Agreement, LICENSEE shall make a report of Licensed Articles on hand and shall pay the appropriate royalties with respect thereto. If

Royalties

So long as this license is exclusive, LICENSEE shall pay

Royalties

Royalties

4. LICENSEE may cancel this Agreement at any time upon ninety (90) days' notice in writing to LICENSOR. Termination of this Agreement pursuant to this or any other paragraph shall not relieve LICENSEE of the obligation to pay accrued royalties.

5. After termination of this Agreement LICENSEE shall not be subject to any estoppel by reason of its having been a LICENSEE.

6. LICENSEE agrees that it will render to LICENSOR with each such royalty payment, a report showing the period for which said payment is made, and the net sales upon which the royalty payment is computed. LICENSEE agrees to keep accurate accounts in sufficient detail to enable the royalties payable hereunder to be determined, and LICENSEE further agrees to permit a Certified Public Accountant selected by LICENSOR and acceptable to LICENSEE to inspect such records at reasonable times during regular business hours for the sole purpose of verifying the accuracy of the reports submitted and payments made under this License Agreement, subject to the condition that

LICENSOR shall give written notice to LICENSEE, within six (6) months following the receipt by LICENSOR of each such quarterly report and royalty payment concerning which verification is desired, and LICENSOR, through its designated Certified Public Accountant, shall proceed promptly with the inspection of said records.

7. Royalties at rates specified in paragraph 3 hereof shall be due and payable quarterly on or before the sixtieth (60th) day following the first day of each of the months of January, April, July and October for the corresponding preceding quarterly period. LICENSEE shall furnish LICENSOR, with each royalty payment, a written statement setting forth the net sales value of the Licensed Articles sold by LICENSEE during the preceding quarterly period and the amount of royalty due and payable to LICENSOR under the terms of this License Agreement, as provided by paragraph 3 hereof.

Royalties

8. LICENSEE may grant sublicenses hereunder providing the license payments due LICENSOR are no less

than those provided herein. In such event LICENSEE shall be responsible for royalty payments by its sublicensees. Any granted sublicenses shall terminate concurrently with this License. LICENSEE shall pay over to LICENSOR as royalty payments computed at the rates specified in subparagraphs b and c of paragraph 2 computed upon the same basis as if LICENSEE had manufactured the Licensed Article.

9. LICENSOR may cancel this Agreement upon default of LICENSEE by giving ninety (90) days' notice to do so, and unless LICENSEE cures the default complained of during such ninety (90) day period; but no such termination shall affect the obligation of LICENSEE to pay royalties or other obligations accrued before the effective date of such notice.

10. EICENSEE shall not use, publish or circulate any advertising matter or literature (other than the foregoing patent marking statement of paragraph 2 hereof upon its Licensed Articles and labels used therewith) containing a reference to the University of Illinois or to the University of Illinois Foundation except with the prior written authorization of LICENSOR as to such reference. Such written authorization may be obtained from the Executive Director of the University of Illinois Foundation, which authorization will not be unreasonably withheld.

11. LICENSOR does not warrant the validity of any Letters Patent of the United States herein licensed

and agreed to be licensed as issued upon the application for Letters Patent of the United States hereinabove identified, or any Letters Patent of the United States resulting from the filing of any divisional, reissue or continuation application thereof, nor does LICENSOR accept any liability with respect to enforcement of the said licensed Letters Patent of the United States, as herein provided, against third party infringers or any liability with respect to defending LICENSEE against infringement of any United States or foreign Letters Patent which may at any time be asserted against LICENSEE. LICENSOR agrees to hold one-half (1/2) of the royalties received in a fund to be employed for protection and enforcement of the licensed patents against infringers, such accumulation to be made until such fund reaches ten thousand dollars ($10,000.00) and thereafter for a period of five (5) years from the date hereof or until no substantial infringement exists, whichever date shall be later. At the end of the aforesaid period, LICENSOR may at its discretion disburse said fund into its own account. In the event that LICENSOR does not reasonably enforce said Letters Patent, LICENSEE shall have the right, if it desires and at its own expense, to institute and prosecute claims against third parties for infringement and may apply one-half (1/2) of royalties to apply against the expense of the same, and may retain any recoveries therein.

12. If any licensed claim is held invalid by the final decision of a court or appropriate tribunal, LICENSEE shall not be required to pay royalties hereunder with respect to the subject matter of that claim unless and until the final decision of another appropriate court finds such claim patentable.

13. In the event of breach of this License Agreement by either party hereto, the party not in default may at its election terminate the same by ninety (90) days' written notice to such effect served upon the other party, the notice to briefly set forth the breach or default relied upon to effect termination. In the event the party in default makes full restitution for the breach or default relied upon within said ninety (90) day period, then this License Agreement shall continue in full force and effect.

14. It is agreed that the rights herein granted and agreed to be granted and the obligations and liabilities here imposed and incurred shall apply with equal force and effect to any wholly owned subsidiary now or hereafter directly owned or controlled by LICENSEE and that the acts done by or on behalf of such subsidiary shall, for the purpose of this Agreement, be deemed to be the acts done by the LICENSEE, as the party directly owning or controlling such subsidiary, but nothing contained herein shall be construed as granting to any subsidiary

any rights or advantages which shall continue after such subsidiary has ceased to be a subsidiary, or has ceased to be directly or indirectly owned or controlled by LICENSEE as herein contemplated. In the event of a sale between LICENSEE or any subsidiary of LICENSEE and a corporation acting otherwise than at arms length, the net selling price shall be computed with respect to the first uncontrolled sale to a person who is acting at arms length.

15. It is further agreed that if LICENSEE becomes bankrupt or insolvent or enters into any composition with creditors, or invokes the provisions of any bankruptcy or insolvency statute, or any law for the relief of debtors now in force or hereafter enacted, this License Agreement and the licenses and rights here granted to LICENSEE shall forthwith terminate and cease.

16. It is further understood and agreed that this License Agreement is not assignable by LICENSEE without the written consent of LICENSOR and that LICENSEE cannot release itself from the obligations hereunder by any assignment or transfer of any hereunder licensed United States Letters Patent or any applications for Letters Patent of the United States, and that, subject to the limitations hereinbefore set forth, this License Agreement, the benefits thereof and the obligations and liabilities imposed thereby shall extend to the successors in business of each of the parties hereto.

17. In the event that this License Agreement is terminated prior to the expiration date of any Letters Patent of the United States under which a right and license is herein granted, LICENSOR agrees that LICENSEE shall have the right to sell or otherwise dispose of, within a period of one (1) year, any stock of Licensed Articles on hand as of the date of termination subject to the payment to LICENSOR of royalty as provided in paragraph 3 hereof.

18. Notices called for hereunder shall be deemed properly given if duly sent by United States first-class mail and addressed, in the case of LICENSOR, to the University of Illinois Foundation, Illini Union Building, Urbana, Illinois, and in the case of LICENSEE, to JFD Electronics Corporation, 6101 Sixteenth Avenue, Brooklyn 4, New York.

19. This Agreement is considered to have been executed and delivered within the State of Illinois and it is the intention of the parties that it shall be construed and interpreted in the light of the laws of the State of Illinois and the patent laws of the United States of America, whichever shall be applicable under the circumstances.

IN WITNESS WHEREOF, each of the parties hereto has caused this document to be executed by its duly authorized officers and with full authorization of its

managing Board of Governors or Board of Directors, as the case may be, and its corporate seal to be affixed hereon on the day, month and year first above written.

UNIVERSITY OF ILLINOIS FOUNDATION

By _____
President

Attest:

_____
Secretary

JFD ELECTRONICS CORPORATION

By _____
Vice President

Attest:

Albert Finkel
PRESIDENT.

_____
Secretary

Sworn to before me this 1 day of June 1964

_____

SEYMOUR W. GELLER
Notary Public, State of New York
No. 24-1390350
Qualified in Kings County
Commission Expires March 30, 1965

45

## LICENSE AGREEMENT

THIS LICENSE AGREEMENT entered into this 1st day of December, 1965, by and between the UNIVERSITY OF ILLINOIS FOUNDATION, a non-profit corporation organized and existing under and by virtue of the laws of the State of Illinois, hereinafter referred to as "LICENSOR," and JFD ELECTRONICS CORPORATION, a corporation organized and existing under and by virtue of the laws of the State of New York, hereinafter referred to as "LICENSEE."

WITNESSETH:

WHEREAS, LICENSOR is the owner of the entire right, title and interest in and to Letters Patent of the United States as follows:

| Inventor(s) | Patent No. | Issued | Title |
|---|---|---|---|
| Dyson | 2,958,081 | 10-25-60 | Unidirectional Broadband Antenna Comprising Modified Balanced Equiangular Spiral |
| DuHamel | 2,985,879 | 5-23-61 | Frequency Independent Antennas |
| Isbell | 3,011,168 | 11-28-61 | Frequency Independent Unidirectional Antenna |
| Mayes & Carrel | 3,108,280 | 10-22-63 | Log Periodic Backward Wave Antenna Array |

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| Inventor(s) | Patent No. | Issued | Title |
|---|---|---|---|
| Carrel & Kayes | 3,150,376 | 9-22-64 | Multi-Band Log Periodic Antenna |
| Kayes & Carrel | Re 25,740 | 3-9-65 | Log Periodic Backward Wave Antenna Array |
| Dyson & Kayes | 3,188,643 | 6-8-65 | Circularly Polarized Omnidirectional Cone Mounted Spiral Antenna |
| Isbell | 3,210,767 | 10-5-65 | Frequency Independent Unidirectional Antennas |

as well as applications for United States Letters Patent as follows:

| Inventor(s) | Serial No. | Filed | Title |
|---|---|---|---|

PENDING PATENT APPLICATIONS

as well as the inventions set forth and described in and by each of the aforesaid Letters Patent of the United States and applications for Letters Patent of the United States; and

WHEREAS, LICENSOR also is the owner of the entire right title and interest in and to Letters Patent of countries other than the United States as follows:

| Country | Inventor | Patent No. | Issued | Title |
|---|---|---|---|---|
| Canada | Mayes & Carrel | 715,685 | 8-10-65 | Frequency Independent Unidirectional Antenna (corresponding to re-issue U.S. 25,[illegible] |

; and

WHEREAS, LICENSOR also is the owner of the entire right title and interest in and to applications for patent in countries other than the United States as follows:

| Country | Inventor | Serial No. | Filing Date | Corresponding U.S. Pat. or Application or [illegible] |
|---|---|---|---|---|

PENDING FOREIGN PATENT APPLICATIONS

; and

WHEREAS, LICENSOR may from time to time after the date on which this agreement comes into force and during the term thereof, acquire additional patents and applications for U.S. Letters Patent and additional applications for patent in countries other than the United States; and

WHEREAS, LICENSOR holds the sole right to grant the LICENSE herein granted and agreed to be granted; and

WHEREAS, the parties hereto did on May 24, 1962 enter into a license agreement related to the said patents and applications for patent and the then applications for patent which have now issued and the said parties, now that patents have issued and experience has been obtained under the prior license agreement, now desire to enter into a more extended license agreement which will insure a reasonable income to LICENSOR for a period of years and make it possible for LICENSEE to undertake a reasonable investment in anticipation of sales over a reasonable number of years; and

WHEREAS, LICENSEE desires to secure and LICENSOR desires to grant, for the term of years hereinafter set forth an exclusive license to manufacture, use or sell, or to have made for its use or sale, apparatus of the type described in and by each of the aforesaid Letters Patent of the United States and application for Letters Patent of the United States and by each of the applications and patents in each country other than the United States.

NOW, THEREFORE, in consideration of the foregoing and the mutual terms and conditions of this LICENSE AGREEMENT and other good and valuable consideration, the receipt and sufficiency of all of which is hereby duly acknowledge, the parties hereto agree as follows:

1.. This AGREEMENT is a substitute for and replaces and terminates all prior agreements between the parties including specifically the prior LICENSE AGREEMENT of May 24, 1962 and any extensions and modifications thereof.

2. LICENSOR hereby grants and agrees to grant to LICENSEE an exclusive non-transferable right and license only in the field of receiving antennas for television and FM broadcasting stations

and antennas for amateur and citizens band transmission and reception in the United States and in all countries other than the United States to make, use or sell or have made for its use or sale any invention described in any of the aforementioned Letters Patent as well as the aforesaid applications for Letters Patent and any invention, acquired by LICENSOR, prior to or during the term or extended term of this agreement which invention shall be subsidiary, auxiliary, useful or necessary to practice or use the inventions herein licensed or which shall be an improvement thereof and any continuation, division, utility model, design or continuation-in-part application relating to said licensed patents or applications and to any reissues of any licensed patents. The components so manufactured, used or sold are herein referred to as "LICENSED ARTICLES".

a. LICENSEE is also granted an option to acquire a non-exclusive license under the licensed patents and inventions for all fields other than the field of the exclusive license granted herein at the same royalty rates but subject to equal treatment with the most favored LICENSEE.

3. LICENSEE shall make the following payments to LICENSOR:

a. With respect to "LICENSED ARTICLES" covered by the claims of any issued patent in the country where made or sold, ROYALTY

b. With respect to "LICENSED ARTICLES" covered by the claims of a pending application in the country where made or sold, but not covered by the claims of any issued

patent (provided that said claims reasonably stem from the disclosure of the pending application and provided that LICENSOR'S attorney shall state to LICENSEE his opinion that the claims should reasonably be allowed). ROYALTY

c. No more than a single royalty shall be paid with respect to any "LICENSED ARTICLE" regardless of the number of patents of the LICENSOR in the United States and countries other than the United States which may be applicable thereto.

d. The percentage royalty rate shall be computed upon the net selling price by LICENSEE of such LICENSED ARTICLES made, and or sold by LICENSEE or made by others for its use or sale, the selling price shall be the invoicing price less discounts, allowance, and returns. Such royalty, however, shall be payable only upon sale of the article except in those cases in which the article is consumed by or for LICENSEE without sale; in such latter cases, royalties shall be computed at LICENSEE'S usual selling price of the article.

e. LICENSED ARTICLES made during the life of a licensed patent covering the same, but not sold until the expiration of said patent, shall be subject to royalty.

f. On termination of this agreement at the end of its term or renewed terms or on termination for any other cause, LICENSEE shall make a report of LICENSED ARTICLES on hand and shall pay royalties with respect thereto.

g. Royalties as provided herein shall be due and payable quarterly on or before the sixtieth (60th) day following the first day of each of the months of January, April, July and October for the corresponding preceding quarterly period. LICENSEE shall furnish LICENSOR, with each royalty payment, a written statement setting forth the actual sales of the LICENSED ARTICLES sold by LICENSEE during the preceding quarterly period and the amount of royalty due and payable under the terms of this LICENSE AGREEMENT.

h. The royalty payments shall be made by the LICENSEE together with reports for each quarterly period.

i. LICENSEE agrees to keep accurate accounts in sufficient detail to enable the royalties payable hereunder to be determined, and LICENSEE further agrees to permit a Certified Public Accountant selected and paid by LICENSOR and acceptable to LICENSEE to inspect such records at reasonable times during regular business hours for the sole purpose of verifying the accuracy of the reports submitted and payments made under this LICENSE AGREEMENT, subject to the condition that LICENSOR shall give written notice to LICENSEE within six (6) months following the receipt by LICENSOR of each such quarterly report and royalty payment concerning which verification is desired and LICENSOR through its designated Certified Public Accountant shall proceed promptly with the inspection of said records during regular business hours adjusting his inspection times to the reasonable convenience of LICENSEE'S personnel.

4. The LICENSE herein granted is and shall be and remain exclusive to LICENSEE during the term of this AGREEMENT and any renewal thereof under the following terms and conditions:

a. There is established below a schedule of minimum annual royalties together with a method for varying the said minimum royalties.

b. In the event that, for any annual period, the payments of royalty by LICENSEE to LICENSOR on account of LICENSEE'S and sublicensees sales shall fall below the minimum scheduled annual royalties for said annual period, then LICENSOR shall have the following option exercisable by LICENSOR by notice in writing to LICENSEE not more than sixty (60) days after the receipt by LICENSOR of the report and payment by LICENSEE with respect to the fourth quarter for each annual period;

i. to maintain the exclusive nature of this License but to require that LICENSEE grant sub-licenses under this AGREEMENT to such antenna manufacturers of LICENSEE'S selection as will bring the total of licensed articles sold in the United States to seventy-five percent (75%) of the total of all antennas sold in the United States and infringing at least one non-adjudicated claim or one adjudicated valid claim of a licensed patent,

and to require that LICENSEE sub-license one competitive manufacturer in each foreign country in which LICENSOR'S licensed patents have issued and are subject to this agreement and where LICENSEE'S share of the market for "infringing" antennas is less than 30% of the market in that country.

A. In the event that LICENSOR shall elect to exercise this option, LICENSEE shall make every reasonable effort to effect such sublicense(s), and LICENSOR agrees to render such assistance as LICENSEE may require in effecting such sublicenses.

c. The schedule of minimum annual royalties as the basis for the option set forth in sub-paragraph b hereof shall be as follows:

SCHEDULE OF MINIMUM ROYALTY

d. In the event of renewal of this agreement beyond K as hereinafter provided, then the minimum annual royalties shall be at K per year as a base; if, at any time after K , either party desires that the said minimum

annual royalty should, in fairness, be adjusted and the other party does not on request agree to the adjustment, the parties agree that either party may submit to the American Arbitration Society, New York, for determination, the establishment of a different minimum annual royalty rate, and the decision of the arbitrators will be binding. Either party may make such a request for adjustment and require such arbitration not more often than once each year; and the decision of the arbitrators may, whenever made, be retroactive to cover the calendar year in which the initial request for adjustment was made. Among the factors which the arbitrators are expected to consider are the number of color television sets sold each year which are presently believed to particularly benefit from and require the enhanced quality of reception afforded by antennas made in accordance with the licensed invention; the, possibly growing, impact of increased use of portable color television sets which are not presently expected to use antennas made in accordance with the licensed invention and, therefore, may decrease the market for licensed antennas; the possibly growing, impact of C.A.T.V. type of reception which substitutes a community antenna for individual antennas and, therefore, may further decrease the market for licensed antennas; and other factors which at the time of arbitration are then known or believed to have an effect on the market for licensed antennas.

5. All LICENSED ARTICLES manufactured and sold by LICENSEE under the terms of this LICENSE AGREEMENT shall

carry such reasonable notice as LICENSOR shall from time to time request in writing which notice LICENSOR warrants will comply with the law.

6. LICENSEE shall have the right to grant sublicenses hereunder; in such event, LICENSEE shall be responsible for transmission to LICENSOR of its share of the royalty payments received from its sublicensees. Any sublicenses shall terminate concurrently with the termination of this License. All of the applicable terms of this License Agreement for the protection of LICENSOR with respect to marking and times of payment, default and termination, reports and payments shall be deemed to be incorporated by reference in such sublicenses and a copy of this AGREEMENT shall be attached to such sublicenses with certain areas blocked out at the discretion of LICENSEE.

a. LICENSEE shall charge any sublicensee a royalty rate no less than that required to be paid by LICENSEE to LICENSOR.

ROYALTY

7. This AGREEMENT shall be effective as of January 1, 1966 and shall terminate DATE unless renewed.

RENEWAL OPTIONS DELETED

a. LICENSEE shall have the option during the period [redacted] to notify LICENSOR of its desire to renew the AGREEMENT for an additional [redacted]

On sending of such notice by LICENSEE, this AGREEMENT shall thereafter be extended to terminate [redacted] and shall operate under the conditions herein set forth and specifically the minimum royalty conditions of paragraph 4.

b. LICENSEE shall, if this AGREEMENT has been extended to [redacted] have the further option to renew the same to expire [redacted] by sending a notice to LICENSOR during the period [redacted] In such event, the LICENSE shall remain exclusive but there shall be no minimum royalty provision.

c. This LICENSE shall be deemed to be a paid-up license (and no further royalties shall be due) with respect to any licensed patents or applications for patent which have been issued or are currently pending as of [redacted] and with respect to any divisional, continuation or reissue patents of such then issued or pending applications on the occurrence of either of the following:

1. [redacted]

2. The payment by or through LICENSEE to LICENSOR of royalties totaling [redacted]

d. With respect to any patent or patents of LICENSOR which may become subject to this LICENSE other than those set forth above, royalties, under this AGREEMENT shall, after ✱ be resumed by LICENSEE with respect to such patents and such products of LICENSEE as fall within the claims of such patents.

8. LICENSEE shall not use, publish or circulate any advertising matter or literature (other than the foregoing patent marking statement of paragraph 2 hereof upon its Licensed Articles and labels used therewith) containing a reference to the University of Illinois or to the University of Illinois Foundation except with the prior written authorization of LICENSOR as to such reference. It is understood that authorization previously granted shall stand. Such written authorization may be obtained from the Executive Secretary of the University of Illinois Foundation, which authorization will not be unreasonably withheld.

9. LICENSEE may cancel this AGREEMENT at any time upon ninety (90) days' notice in writing to LICENSOR. Termination of this AGREEMENT pursuant to this or any other paragraph shall not relieve LICENSEE of the obligation to pay accrued royalties.

10. After termination of this AGREEMENT, LICENSEE shall not be subject to any estoppel by reason of its having been a LICENSEE.

11. LICENSOR may cancel this AGREEMENT upon default of LICENSEE by giving ninety (90) days' notice to do so.

and unless LICENSEE cures the default complained of during such ninety (90) day period; but no such termination shall affect the obligation of LICENSEE to pay royalties or other obligations accrued before the effective date of such notice.

12. LICENSOR does not warrant the validity of any Letters Patent of the United States herein licensed and agreed to be licensed as issued upon the application for Letters Patent of the United States hereinabove identified, or any Letters Patent of the United States resulting from the filing of any divisional, reissue or continuation application thereof, nor does LICENSOR accept any liability with respect to enforcement of the said licensed Letters Patent of the United States, as herein provided, against third party infringers or any liability with respect to defending LICENSEE against infringement of any United States or foreign Letters Patent which may at any time be asserted against LICENSEE.

13. LICENSOR agrees to hold one-half (1/2) of the royalties received in a fund to be employed for protection and enforcement of the licensed patents against infringers, such accumulation to be made until such fund reaches ten thousand dollars ($10,000.00), and thereafter for a period of five (5) years from the date hereof or until no substantial infringement exists, whichever date shall be later. At the end of the aforesaid period, LICENSOR may at its discretion disburse said fund into its own account.

14. In the event that LICENSEE shall call the attention of LICENSOR in writing to an infringing device made and sold by a competitor of LICENSEE and shall demand that an action for infringement be brought by LICENSOR with respect thereto and in the event that LICENSOR shall fail to institute such action within thirty (30) days after sending of such notice, then LICENSEE shall have the right at its own expense to institute and prosecute an action with respect to such infringement and may apply one-half (1/2) of royalties to the expense of the same, and payment shall be reduced accordingly.

From any such recovery, LICENSEE may further reimburse itself for its expenses; if any funds are then left, then from such funds in said recovery, LICENSEE shall pay LICENSOR the royalties previously withheld with respect to or on account of such action; if thereafter, any funds remain from such recovery, that shall be divided evenly between LICENSOR and LICENSEE.

This right of LICENSEE to send notice and demand for action and to bring action for infringement shall not be limited to a single action for infringement but shall extend to such actions against such parties as LICENSEE deems necessary, not in excess of ** at any one time, provided that at no one time shall such actions involve duplication of issues against the same ultimate party in interest. In the event, however, that LICENSEE shall elect to bring an action which shall increase the number of pending actions brought by LICENSEE

** CONFIDENTIAL BUSINESS INFORMATION DELETED

above the said number, it may do so; but in such latter event, it may withhold only such part of the royalty as will leave the LICENSOR [redacted] of the entire royalty due LICENSOR in any one year, after deduction of LICENSEE'S and LICENSOR'S expenditures and commitments for expenditures for litigation; it being understood, however, that LICENSOR'S such expenditures and commitments for expenditures will not for this purpose exceed [redacted] of the royalties due in any one year.

15. If any licensed claim is held invalid by the final decision of a court or appropriate tribunal, LICENSEE shall not be required to pay royalties thereunder with respect to products covered by that claim unless and until the final decision of another appropriate court finds such claim patentable.

16. In the event of breach of this License Agreement by either party hereto, the party not in default may at its election terminate the same by ninety (90) days' written notice to such effect served upon the other party, the notice to briefly set forth the breach or default relied upon to effect termination. In the event the party in default makes full restitution for the breach or default relied upon within said ninety (90) day period, then this License Agreement shall continue in full force and effect.

17. It is agreed that the rights herein granted and agreed to be granted and the obligations and liabilities here imposed and incurred shall apply with equal force and

effect to any wholly owned subsidiary now or hereafter directly owned or controlled by LICENSEE and that the acts done by or on behalf of such subsidiary shall, for the purpose of this AGREEMENT, be deemed to be the acts done by the LICENSEE, as the party directly owning or controlling such subsidiary, but nothing contained herein shall be construed as granting to any subsidiary any rights or advantages which shall continue after such subsidiary has ceased to be a subsidiary, or has ceased to be directly or indirectly owned or controlled by LICENSEE as herein contemplated. In the event of a sale between LICENSEE or any subsidiary or LICENSEE and a corporation acting otherwise than at arms length, the net selling price shall be computed with respect to the first uncontrolled sale to a person who is acting at arms length.

18. It is further agreed that if LICENSEE becomes bankrupt or insolvent or enters into any composition with creditors, or invokes the provisions of any bankruptcy or insolvency statute, or any law for the relief of debtors now in force or hereafter enacted, this License Agreement and the licenses and rights here granted to LICENSEE shall forthwith terminate and cease.

19. It is further understood and agreed that this License Agreement is not assignable by LICENSEE without the written consent of LICENSOR except to a successor of the entire business of LICENSEE related to television antennas and that LICENSEE cannot release itself from the obligations hereundor by any assignment or transfer of any hereundor

licensed United States Letters Patent or any applications for Letters Patent of the United States, and that, subject to the limitations hereinbefore set forth, this License Agreement, the benefits thereof and the obligations and liabilities imposed thereby shall extend to the successors in business of each of the parties hereto.

20. In the event that this License Agreement is terminated prior to the expiration date of any Letters Patent of the United States under which a right and license is herein granted, LICENSOR agrees that LICENSEE shall have the right to sell or otherwise dispose of, within a period of one (1) year, any stock of Licensed Articles on hand as of the date of termination subject to the payment to LICENSOR of royalty as provided in paragraph 3 hereof.

21. University Patents Inc. of Illinois, Chicago, Illinois, is hereby appointed by LICENSOR as administrator of this AGREEMENT on behalf of LICENSOR. Notices and payments required hereunder shall be deemed properly given if duly sent by United States first-class mail and addressed, in the case of LICENSOR: University Patents Inc. of Illinois, 30 West Monroe Street, Chicago, Illinois; and in the case of LICENSEE: JFD Electronics Corporation, 15 Avenue at 62 Street, Brooklyn, New York 11219.

22. This AGREEMENT is considered to have been executed and delivered within the State of Illinois, and it is the intention of the parties that it shall be construed

and interpreted in the light of the laws of the State of Illinois and the patent laws of the United States of America, whichever shall be applicable under the circumstances.

23. If LICENSOR shall acquire after the date on which this agreement comes into force and during the term thereof, any patent rights which fall within the field of receiving antennas for television and FM broadcasting stations and antennas for amateur and citizens band transmission and reception in the United States or in any other country, LICENSEE shall have the opportunity to include those after-acquired inventions in this agreement. If the acquisition of said after-acquired inventions obligate LICENSOR to impose terms and conditions over and above those of this agreement or shall require LICENSOR to pay to or share royalties with, the person from whom such patent rights are acquired by LICENSOR, LICENSEE shall have an option to have such after-acquired patent rights included with the licenses granted in paragraph 2 hereof. Within sixty (60) days after such acquisition LICENSOR shall advise LICENSEE of the general nature thereof and of the additional terms and conditions, if any, involved in the acquisition of such rights, and shall forward to LICENSEE copies of any and all issued Letters Patent or patent applications involved in the acquisition. LICENSEE shall then have the right, within sixty (60) days of the notice from LICENSOR to include such patent rights in the licenses above granted by either tendering to LICENSOR a reimbursement of the expenses incurred in such acquisition or by agreeing to assume the

additional obligations of LICENSOR. If, at any time during said sixty (60) day period LICENSEE so requests LICENSOR in writing, LICENSOR will forward to LICENSEE all patent application papers and other material in its possession which relate to the patent rights in question, in which case the termination date of the period will be extended when necessary so that LICENSEE will have no less than sixty (60) days after receipt as such applications and other material to make its election. Failure of LICENSEE to elect within the applicable time period shall exclude such patent rights from the LICENSES herein granted. This paragraph 23 is not intended to require any additional obligation consideration when it pertains to any after-acquired inventions that emanate from the University of Illinois. The same sixty (60) day provision shall apply but LICENSEE shall not be required to assume any additional obligation in order to elect to include after-acquired inventions emanating from the University of Illinois.

IN WITNESS WHEREOF, each of the parties hereto has caused this document to be executed by its duly authorized officers and with full authorization of its managing Board of Governors or Board of Directors, as the case may be, and its corporate seal to be affixed hereon on the day, month and year first above written.

UNIVERSITY OF ILLINOIS FOUNDATION

Attest:

Ray E. Snyder
Secretary Vice President

By _____
President,

JFD ELECTRONICS CORPORATION

Attest:

Edward Finkel
Secretary Vice-President

By Albert Finkel
President

HOME FURNISHINGS DAILY, MONDAY, APRIL 18, 1966

# Antenna Patent Suit Hits Jerrold

CHICAGO. — The University of Illinois Foundation, Urbana, charged in Federal Court that Jerrold Electronics Corp., Philadelphia, and R. Cooper, Jr., Inc., here, make or cause manufacture and sale of radio and TV antennas that infringe two of its patents.

The patents are Nos. 3,150,376, for a multiband, log-periodic antenna, and 3,210,767, for a frequency-independent, unidirectional antenna.

The suit asks for injunctions and an accounting and award of damages.

Merriam, Marshall, Shapiro & Klose represents the foundation.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION
DEFENDANT'S EXHIBIT
DOROTHY L. [illegible]
OFFICIAL COURT REPORTER

(14)

WELLER ELECTRONIC SALES, INC. DATE: May 2, 1966

INTER-OFFICE CORRESPONDENCE

TO: Mr. Dick Helhoski, Blonder-Tongue Labs.

FROM: Bill Weller

SUBJECT: Main Line Cleveland
1260 E. 38th Street
Cleveland, Ohio

Dear Dick:

I am forwarding to you a copy of the JFD mailing which was received by Main Line.

Would you please write to Mr. Adolph Friedman at Main Line informing him that you will protect his company against any patent infringement suit that JFD will bring against them due to their handling our Ranger antennas.

Thanks.

Sincerely yours,

Bill Weller

BW:ts
encl:

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
BEFORE JUDGE FOREMAN
DEFENDANT EX. NO. ##4
DOROTHY L. BROCKENBUSH
OFFICIAL COURT REPORTER

FILED
AUG 27 1968

57

# SALES BULLETIN

TO: ALL JFD DISTRIBUTORS April 19, 1966

FROM: ED FINKEL

SUBJECT: UNIVERSITY OF ILLINOIS FOUNDATION SUES:

BLONDER-TONGUE LABORATORIES. INC.

CHANNEL MASTER CORPORATION

JERROLD ELECTRONICS CORP.

FOR LOG PERIODIC ANTENNA BASIC PATENT INFRINGEMENT

The above firms now join Finney Company and Winegard Company in the list of manufacturers being sued by the University of Illinois Foundation for patent violations.

A reprint of the official press release, and the article from Home Furnishings Daily of April 18, 1966, specify the actions taken against the patent violators.

The Foundation is taking vigorous action in the courts to sue all violators of the basic Log Periodic Patents. JFD is the EXCLUSIVE licensee of the Foundation authorized to manufacture antennas under these basic patents.

If emulation is the sincerest form of flattery, then JFD and its Franchised Distributors must be selling the finest TV and FM antennas on the market today. The fantastic acceptance and success of the whole JFD LPV antenna line attests to the validity of this conclusion.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION
DEFENDANT'S EX. NO. 58
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

224 Illini Union · Urbana, Illinois

# UNIVERSITY OF ILLINOIS FOUNDATION

April 7, 1966

Hjalmar W. Johnson, President of the University of Illinois Foundation, revealed today that the Foundation had filed civil actions in the Federal District Court in Chicago against Blonder-Tongue Laboratories, Inc., Allied Radio Corporation, Channel Master Corporation, and Electronic Distributors, Inc., charging infringement of one of the Foundation's Log Periodic Antenna patents.

Mr. Johnson stated that the Log Periodic Antenna Inventions constitute one of the most important new developments in the antenna industry and that the Foundation Antenna licensing programs is one of the most important income sources for the Foundation.

Earlier this year the Foundation filed a civil action in the Federal District Court of Iowa against the Winegard Company, charging infringement.

The JFD Electronics Corporation of Brooklyn, New York, has an exclusive license under the patents in the field of receiving antennas for television and FM broadcasting stations, and antennas for amateur and citizens band transmission and reception. All other fields are licensed non-exclusively by the Foundation.

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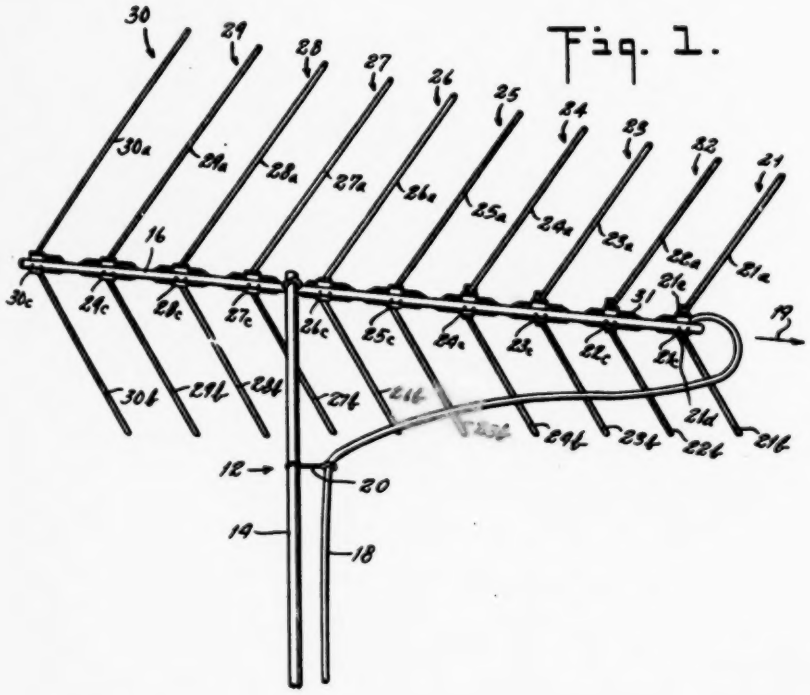
JFD EXHIBIT 2A.

April 16, 1963 H. GREENBERG 3,086,206

END FIRE PLANAR DIPOLE ARRAY WITH LINE TRANSPOSITION BETWEEN DIPOLES AND IMPEDANCE INCREASE TOWARDS FEED

Filed Oct. 19. 1960 4 Sheets-Sheet 1

Fig. 1.



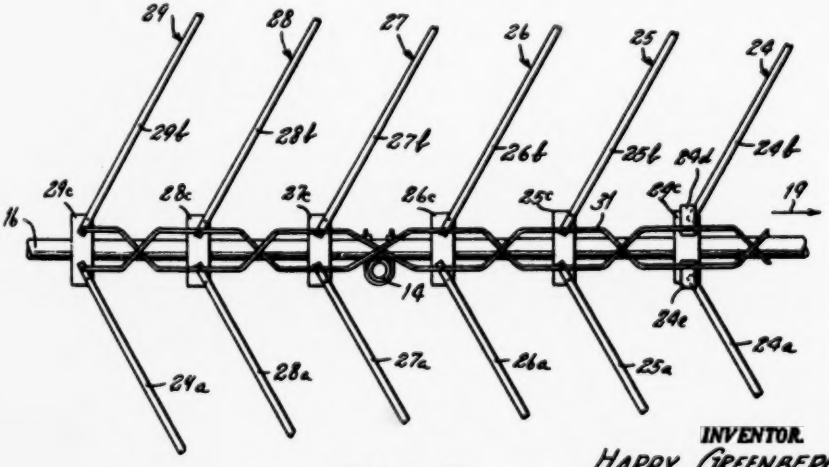




Fig. 2.

INVENTOR.
HARRY GREENBERG
BY Darby & Darby
ATTORNEYS

April 16, 1963 H. GREENBERG 3,086,206
END FIRE PLANAR DIPOLE ARRAY WITH LINE TRANSPOSITION
BETWEEN DIPOLES AND IMPEDANCE INCREASE TOWARDS FEED
Filed Oct. 19. 1960 4 Sheets-Sheet 2

Fig. 3.

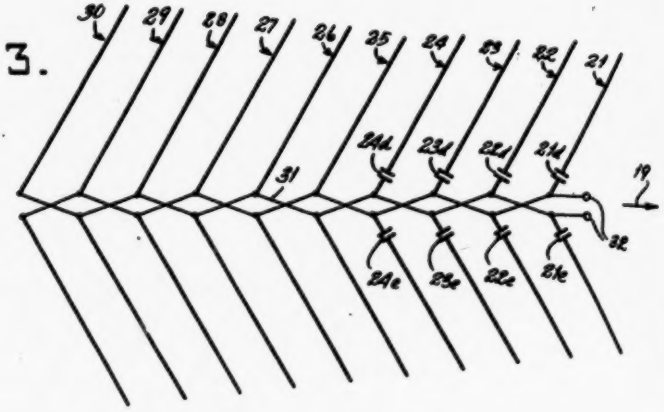


Fig. 4.

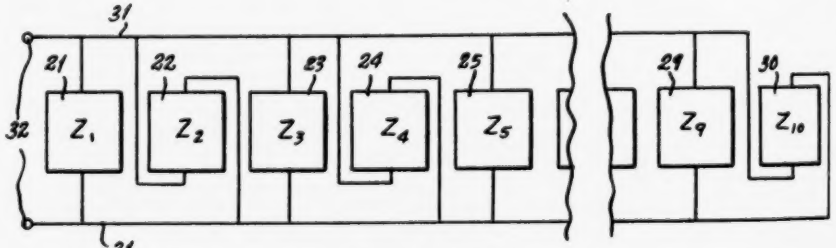



Fig. 5.

INVENTOR.
HARRY GREENBERG
BY Darby & Darby
ATTORNEYS

April 16, 1963 H. GREENBERG 3,086,206
END FIRE PLANAR DIPOLE ARRAY WITH LINE TRANSPOSITION
BETWEEN DIPOLES AND IMPEDANCE INCREASE TOWARDS FEED
Filed Oct. 19. 1960 4 Sheets-Sheet 3

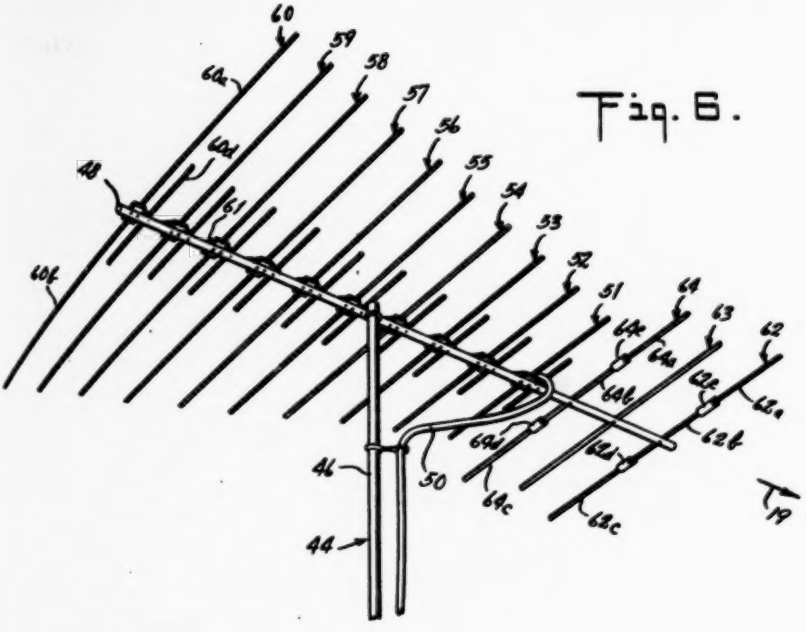



Fig. 6.

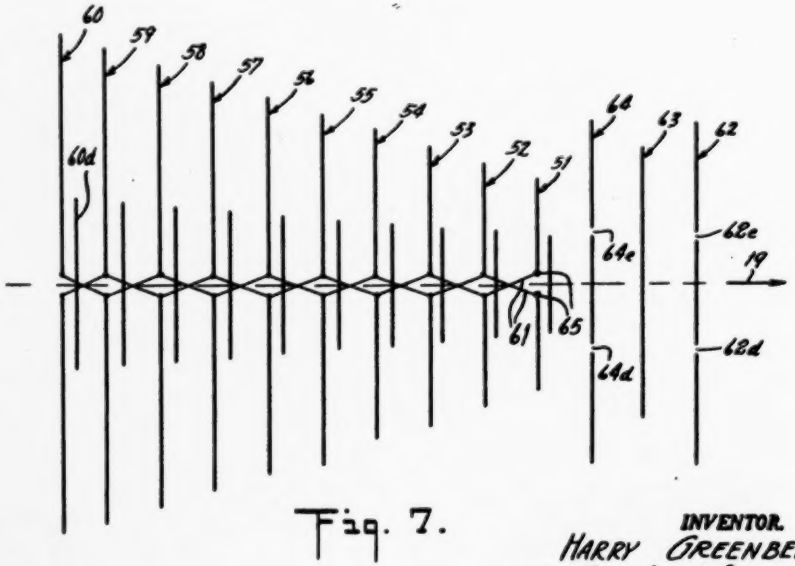



Fig. 7.

INVENTOR.
HARRY GREENBERG
BY Darby & Darby
ATTORNEYS

April 16, 1963 H. GREENBERG 3,086,206
END FIRE PLANAR DIPOLE ARRAY WITH LINE TRANSPOSITION BETWEEN DIPOLES AND IMPEDANCE INCREASE TOWARDS FEED
Filed Oct. 19, 1960 4 Sheets-Sheet 4

Fig. 8.

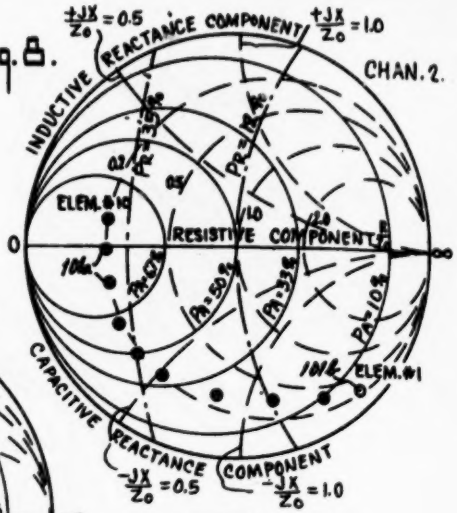



Fig. 9.

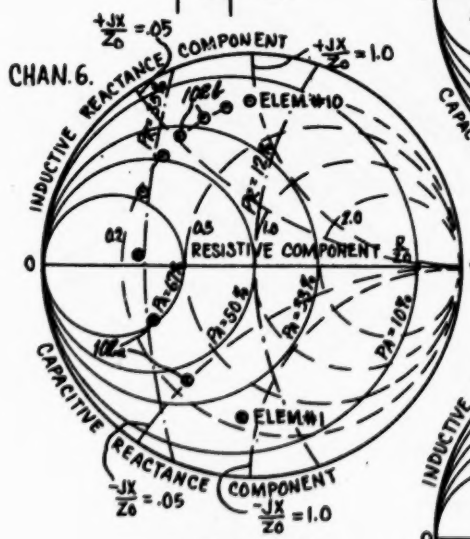



Fig. 10.

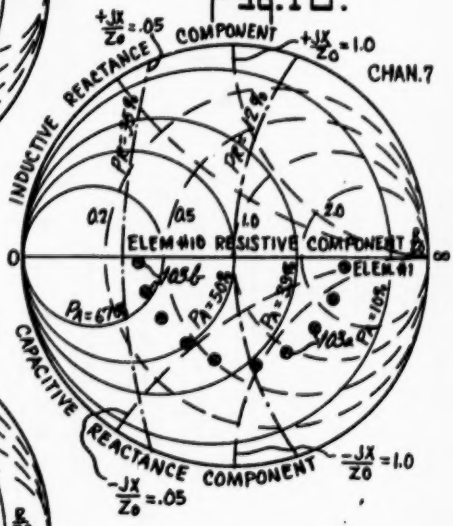
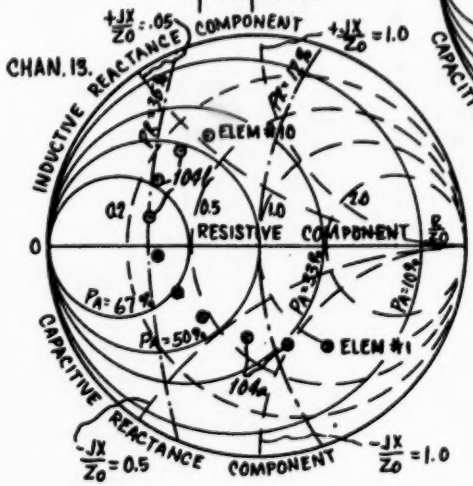



Fig. 11.




INVENTOR.
HARRY GREENBERG
BY Darby & Darby
ATTORNEYS

United States Patent Office

3,086,206
Patented Apr. 16, 1963

ISSUED
June 16, 1964
3,086,604

3,086,206

# END FIRE PLANAR DIPOLE ARRAY WITH LINE TRANSPOSITION BETWEEN DIPOLES AND IMPEDANCE INCREASE TOWARDS FEED

Harry Greenberg, Kerhonkson, N.Y., assignor to Channel Master Corporation, Ellenville, N.Y., a corporation of New York

Filed Oct. 19, 1960, Ser. No. 63,520
9 Claims. (Cl. 343—815)

The present invention relates to antennas for the propagation or reception of electromagnetic energy of radio frequencies and more particularly to such antennas adapted for use in noncontiguous frequency bands such as the high band and the low band portions of the frequencies allocated to VHF television, or in very wide frequency bands, where the ratio of the highest frequency to the lowest frequency may be 3 or more.

The wide-spread use of television receivers has brought about a demand for highly developed television receiving antennas, particularly for use in areas far removed from transmitters from which it is desired to receive television broadcasts. Antennas for these remote areas are customarily called fringe-area antennas. A prime requisite for such an antenna is that it have a high degree of signal gathering ability. This ability is commonly referred to in terms of gain, gain being defined as the antenna's signal-gathering ability compared to a standard dipole antenna, and usually expressed in decibels (db). Another important requisite is that the antenna be able to discriminate against broadcasts from other than desired directions. This requires that the receptivity pattern have essentially a single major lobe or at most two oppositely directed lobes, of as much sharpness as is practicable or desirable for particular situations.

Antennas are inherently frequency selective devices which respond best to a limited range of frequencies and are substantially ineffective outside of this range. While one could provide a separate television antenna for each television channel to be received, this would obviously be impractical. It is, of course, most desirable to have a single antenna for all television channels. Such an antenna is customarily known as an all-channel antenna. The manner in which television frequencies in the VHF television band have been allocated has rendered it most difficult to provide an efficient all-channel VHF television antenna.

While there are only twelve VHF television channels, each six megacycles wide, these channels are not allocated to wholly contiguous frequency ranges, but are divided into a low band extending from 54 megacycles to 88 megacycles and a high band extending from 174 megacycles to 216 megacycles. Thus the highest VHF television frequency of 216 megacycles exceeds the lowest VHF television frequency of 54 megacycles by a factor of four. This band-width has heretofore rendered exceedingly difficult the design of a single all-channel antenna.

By the present invention a television antenna for all VHF television channels is provided which is of remarkable efficiency. This is accomplished by providing a front-fed, in-line television antenna with multiple driven elements which effectively covers the low band portion of the VHF television frequencies, operating throughout the low band in a single mode. Features are included which render the antenna elements and the array taken as a whole also effective on the high-band portion of the VHF television range.

Suitable operation of the antenna on the high-band is achieved by especially designing the individual element configuration to obtain a good radiation or reception pattern on the high-band channels, and, at the same time, providing a particular impedance relationship between the elements of the array on the high-band which provides a high efficiency for the array as a whole; this is accomplished while maintaining proper low band operation.

The basic configuration of the antenna also provides an exceptionally good directivity characteristic and "front-to-back-ratio." This ratio is a measure of the ability of the antenna to reject signals from directions opposite to those of the desired signal. This is a particularly important consideration at the present time in fringe areas due to the increased number of television transmitters, and due to the fact that, in fringe areas, transmitters within the range of a particular receiver will usually be located in several different directions. Thus a high degree of directivity and a high "front-to-back-ratio" is very desirable for eliminating both co-channel and adjacent channel interference. The high front-to-back-ratio of antennas according to the present invention is provided in a substantial part by the transposition-type of connection of the transmission line and the front-fed arrangement of the array, for reasons which will be more fully explained hereinafter.

The antennas provided by the present invention in particular represent an improvement over antennas disclosed in U.S. Patent No. 2,817,085 issued Dec. 17, 1957, to Jerome Schwartz and Yuen Tze Lo, but as will later be explained, some basic theories upon which the antennas of the aforementioned Schwartz et al. patent are based may be utilized in antennas according to the present invention.

In addition to providing the advantages and features described above, it is an object of the present invention to provide a high-gain television antenna having multiple in-line active elements, which antenna is effective on two separated frequency bands, and particularly where such two bands bear approximately a harmonic relationship.

It is another object of the present invention to provide a television antenna having several in-line active dipole elements fed from the front of the array by a transmission line.

It is still another object of the present invention to provide an antenna of the foregoing type wherein the absorption of energy by the individual elements is successively greater in a direction away from the feed point or front of the antenna for two or more of the elements at all frequencies within the operating frequency range of the antenna.

It is still another object of the present invention to provide an antenna of the foregoing type wherein the transmission line connecting the antenna elements has a transposition between each antenna element and its succeeding element.

It is a further object of the present invention to provide a television antenna of the foregoing type wherein the antenna elements are caused to have a good reception pattern or directivity by use of a relatively short parasitic element closely spaced in front of each simple dipole element.

It is a still further object of the present invention to provide a television antenna of the previously described type wherein good directivity is provided by use of V-shaped active elements with the apex of each V pointing in the direction opposite to the direction of maximum effectiveness of the antenna.

Other objects and advantages of the present invention will be apparent from a consideration of the following description in conjunction with the appended drawings, in which:

FIGURE 1 is a perspective view of one form of antenna array according to the present invention;

FIGURE 2 is a plan view of a portion of the antenna array of FIGURE 1;

FIGURE 3 is an electrical schematic diagram of the antenna of FIGURE 1;

FIGURE 4 is a schematic diagram of a V-type dipole showing the current distribution for the dipole;

FIGURE 5 is a schematic circuit diagram presented to aid in the explanation of a theory of operation of the antenna of FIG. 1;

FIGURE 6 is a perspective view of an alternative form of antenna according to the present invention;

FIGURE 7 is an electrical schematic diagram of the antenna of FIGURE 6; and

FIGURES 8 through 11 are Smith chart impedance diagrams of the antenna elements of a typical antenna according to the present invention, presented to aid in the explanation of a theory of operation of the antenna.

Referring to FIGURES 1 and 2, an antenna array 12 is shown having a mast 14 and a horizontal boom 16 for the support of a plurality of active antenna elements. A signal transmission line 18 is provided which is supported by suitable supports shown at 20 for example. Line 18 connects the antenna to a receiver or transmitter, as the case may be.

The antenna array comprises illustratively ten active dipole elements numbered 21 through 30 reading from right to left in FIGURE 1. These progressively vary in length, from the shortest element 21 to the longest element 30. The signal transmission line 18 is connected to the shortest dipole element 21 (to the right in FIGURE 1). The dipole element 21 is at the front of the antenna, or in other words, the direction of maximum effectiveness of the antenna is toward the right in FIGURE 1, as shown by the arrow 19.

Throughout this discussion, the antenna arrays according to the present invention may be considered from time to time as transmitting antennas. This is a technique often employed in the antenna art, and by the principle of reciprocity for transmitting and receiving antennas, conclusions reached by considering the antenna as a transmitting antenna are also known to be applicable for the antenna utilized as a receiving antenna. Obviously, antennas according to the present invention may be utilized either as transmitting antennas or as receiving antennas, but are primarily designed for use as television receiving antennas.

Each of the antenna elements 21 to 30 comprises respectively a right arm 21*a* to 30*a*, and a left arm 21*b* to 30*b*.

The pair of arms of each antenna element are disposed at an angle to form a V, with the apex of the V pointing in a direction opposite to the direction 19 of maximum effectiveness of the antenna. In the particular example illustrated, the angle of each of the V's is the same, although this need not necessarily be the case.

A two-wire transmission line harness 31 is provided for connecting antenna elements 21 to 30 in parallel with one another and to the signal transmission line 18. The two-wire transmission line harness 31 will be noted to have a transposition between each pair of successive antenna elements so that alternate ones of the antenna elements 21 to 30 are connected electrically in opposite sense to the transmission line harness 31. The advantage of this connection will be more fully explained hereinafter in the course of explanation of the operation of the antenna.

The physical structure of the antenna 12 is shown in greater detail in FIGURE 2, and for convenience, the connecting structure for antenna elements 23 and 24 will be described in more detail, with the understanding that other elements of the antenna have connecting structure similar to one or the other of elements 25 and 24.

The arms 25*a* and 25*b* of antenna element 25 are connected to boom 16 by means of an insulating support 25*c* and are thus electrically insulated from each other and from the antenna boom 16.

The inner end of arm 25*a* and the inner end of arm 25*b* are connected to respective wires of the two-wire transmission line harness 31. Elements 26 to 30 are of generally similar construction to element 25, the portions of each being assigned the same reference number as the element itself, with a suffix letter corresponding to those assigned to the portions of element 25.

Element 24 is arranged with each of the arms 24*a* and 24*b* connected at its inner end to an insulating support 24*c* by riveting, bolting, or any other suitable connection, the precise nature of which does not form a part of the present invention. The inner ends of arms 24*a* and 24*b* are not, however, connected directly to respective wires of the transmission line harness 31, but are rather connected through respective capacitors 24*d* and 24*e* to respective wires of the two-wire transmission line 31. Capacitors 24*d* and 24*e* may be of any conventional type provided with a suitable weather-proof enclosure or other wire immune to weather variations. Exemplary capacitance values for the capacitors utilized in the antenna of FIGURES 1 and 2 is given in tabular form hereinafter with other dimensions and characteristics of the antenna.

The construction of antenna elements 21 to 23 is generally similar to that described for element 24 and corresponding components of the elements 21 to 23 have been given reference numbers consisting of the reference number of the antenna element plus a suffix letter corresponding to that of the corresponding component of antenna element 24.

The electrical characteristics of the antenna of FIGURE 1 are represented in FIGURE 3 wherein it will be seen that an antenna is provided having a multiplicity of active aligned V-shaped dipole elements (in this case ten) interconnected by an alternately transposed transmission line harness 31. Certain of the dipole elements are provided with capacitors in series with the arms thereof at their inner ends (in this specific illustrative example, four active elements 21 to 24 are so provided with capacitors). The capacitors function to permit proper operation on the high band as well as the low band, as described more in detail below. It will be noted from FIGURE 3 that the signal transmission line 18 is connected to the antenna at terminals 32 at the front of the antenna.

In explaining the operation of the antenna it is desirable to first explain the operation of a single one of the V-dipole elements. It is an important feature of the present invention, where the antenna is to be used as a dual-band V.H.F. television antenna, to construct each of the dipole elements to have good directivity and reception pattern shape on both bands. This is accomplished in the embodiment of FIG. 1 by arranging each dipole element with its arms tilted slightly forward toward the source of received signals. VHF television signals are broadcast in two separate bands with channels 2 through 6 being in the lower band between 54 and 88 megacycles per second and channels 7 through 13 in the upper band between 174 and 216 megacycles per second. Approximately half of the television channels therefore have frequencies which are roughly three times the frequencies of the other half of the television channels. It has been found that the response curve of a dipole antenna as a function of frequency for dual-band VHF television sig-

nals can be improved by tilting the arms of the dipole forward by an angle of approximately 30 to 40 degrees, leaving a subtended angle of 120 to 100 degrees between the arms.

A dipole which is one-half wavelength in the lower band will be approximately three-half wavelengths long in the upper band. A dipole 36 is shown in FIG. 4 with dashed lines 37 indicating current distribution for low band signals and dotted lines 38 indicating current distribution for high-band signals. In a straight dipole, three-halves wavelength operation results in a clover leaf radiation pattern with a forward null and 45° oriented side lobes. Tilting the arms forward tends to produce a centered forward lobe and eliminate the lobes oriented 45° from center forward.

Previously, multiple-element end-fire arrays have been suggested, in which the several elements have had different resonant frequencies in order to operate at more than one frequency. Such antennas have had relatively limited band width. While the band width could be increased by addition of further elements, to expand the array enough to cover a frequency range of the order of 300% or more leads to an impracticable array because of the large number of elements which would be required.

Similarly, while individual dual-band antenna elements such as V-dipoles have been known, it is not generally possible to convert a multi-element single-band antenna array to a dual-band antenna array simply by substituting dual-band elements for the elements in the multi-element single-band array; this is believed to be caused by the erratic impedance relations which then exist among the various elements, particularly at high-band frequencies, and to the effects of higher-mode operation at such frequencies, which normally cause degraded reception patterns and gain.

The present invention has overcome these disadvantages and has solved the problem of providing a dual-band antenna effective on both the high and low band portions of the VHF television frequency allocation or effective over a band width of the order of 4 to 1 or more.

The antenna of FIGURE 1 belongs to the broad family of end-fire antenna arrays. An important feature of the present antenna is that it is fed from the front end (i.e. the signal line 18 is coupled there) and transpositions are provided in the interconnecting transmission line harness 31 between adjacent antenna elements. It should further be noted that the antenna of FIGURES 1 to 3 is not of the type where the active elements are respectively designed to be individually resonant each at a particular channel or portion of the antenna operating frequency range, but rather, at each frequency range portion or television channel several active elements cooperate to increase signal gathering ability. This cooperation is achieved by causing those antenna elements which are active to have individual impedances which are graduated and increase as one progresses toward the feed point of the antenna array.

Antennas according to the present invention with a transposition-type of interconnecting transmission line harness provide an exceptionally good front-to-back-ratio even as compared with previously successful end-fire antenna arrays such as that shown in Schwartz et al. Patent No. 2,817,085. An intuitive understanding of how the antenna operates to provide superior front-to-back ratio may be acquired from the following explanation. The antenna will be considered as a transmitting antenna to aid in the explanation. Referring to FIGURE 3, consider a particular signal transmitted to the input terminals 32. This signal will be partially absorbed and radiated by the first antenna element 21 while a portion of the signal will continue along transmission line harness 31 and will then be partially absorbed and radiated by antenna element 22. Obviously it is desirable that the wave radiated from antenna element 22 toward the right in FIGURE 3 should arrive at antenna element 21 in phase with the wave radiated from that element. Three major factors affect this relationship: the length of transmission line harness 31 between the two active elements, the free space distance between the two elements, and the 180° phase shift imparted by the transposition in transmission line harness 31. The first two of these factors can readily be adjusted so that the total phase shift is 360° and so that the waves radiated to the right by antenna elements 21 and 22 are respectively in phase at each point along direction 19. Similar considerations would apply to the remaining pairs of elements.

To achieve a high front-to-back-ratio it is conversely desirable that little or no energy be radiated to the left in FIGURE 3. This will be accomplished if the radiation from the various elements is approximately equal and the radiation from adjacent elements is substantially 180° out of space phase, since the velocity of propagation in transmission line harness 31 is equal to the free space velocity of propagation and the length of transmission line harness 31 is substantially equal to the spacing between adjacent elements 21 and 22. In such a case, the phase delay of the wave from element 21 to any point differs 180° from that of element 22 due to the phase shift in the transposed transmission line of length equal to the element spacing. It is also noteworthy that the antiphase condition for adjacent elements for backward propagation obtains substantially without regard to frequency, which provides the good front-to-back-ratio for all elements. In view of the inherently high front-to-back-ratio of the antenna array according to the present invention, it may not be necessary to provide a parasitic reflector element, and in fact, no such element is required in the antenna of FIGURES 1–3.

From the foregoing explanation, it will be seen that the front-fed, end-fire antenna array with transpositions in the interconnecting transmission line harness between adjacent antenna elements is well adapted to provide an efficient VHF television antenna with high front-to-back-ratio. However, without special provision according to other features and aspects of the present invention, such an antenna would be suitable for use only for a relatively limited band such as the low band of VHF television broadcasting.

It might be thought that such a single-band antenna could be readily adapted for dual-band operation for both the high and low bands of the VHF television frequency allocations, merely by replacing each simple element with a dual-band element. However, the complexity of the interactions of the elements under the widely differing frequencies encountered in such an antenna places numerous difficulties in the way of extending the operation of such an antenna to dual-band operation. Important impedance relationships which may exist in the low band, would not automatically exist in the high band, where each active dipole element operates in a harmonic mode and hence at a different region of its impedance characteristic. By the present invention it has been made possible to utilize a front-fed end-fire antenna array on the low band as well as the high band, by use of features providing proper impedance relationships both on the high band and on the low band.

In accordance with the present invention, a desired impedance relationship between the various antenna active elements on both bands may be achieved by determination of two parameters, for at least some of the elements, one of which desirably is the length of the antenna element. In the embodiment of the invention illustrated in FIGURES 1–3, utilizing V-type dual-band antenna elements, a capacitor is inserted in series with each arm of certain antenna elements at their inboard ends. The capacitance value of each capacitor is chosen in relation to the element length, to determine the impedance value of its associated antenna element so as to obtain a desired relationship be-

tween the various elements for operation in both bands. A desirable way to design the antenna is to first select element lengths suitable for high band operation. Then, since the effect produced by the capacitors is relatively small for the high-band frequencies, either the selected length will remain unchanged, or a compensating adjustment can be made in the length of the dipole arms to completely off-set the effect of the capacitor at high-band frequencies.

Other means can be utilized to provide the desired impedance relationship in both bands. In FIGURES 6 and 7 for example, an alternative embodiment of the invention is illustrated utilizing substantially straight rather than the V-shaped dipole elements, with each straight dipole having a relatively close-spaced short, parasitic element in front of it.

The antenna of FIGURES 6 and 7 is otherwise generally similar to the embodiment of FIGURES 1 to 3. The antenna array **44** has a supporting mast **46** and a horizontal boom **48**. A signal transmission line **50** is provided to connect the antenna array to a utilization device such as a television receiver.

The array **44** has ten active elements **51** to **60** of progressively varying length, each comprising substantially co-linear arms **51***a* and **51***b* through **60***a* and **60***b*, inclusive. The active elements **51** to **60** are interconnected by an interconnecting transmission line harness **61** in a fashion similar to that shown in FIGURES 1 to 3. Insulating supports **51***c* to **60***c* are provided for securing the arms of the antenna elements in insulated relation to the boom **48** and to each other. Each of the dipoles **51** to **60** is provided with a respective close-spaced short parasitic element **51***d* to **60***d*, on the front side of the dipole.

The short parasitic elements **51***d* to **60***d* do not substantially affect the operation of the dipoles **51** to **60** on the low-band frequencies; hence the lengths of the dipole arms can be selected as appropriate for low-band operation, and to the extent that the operation is affected compensation can be made by slightly altering the lengths of the dipole arms. The parasitic elements **51***d* to **60***d* are effective at high-band frequencies to provide a sharp directivity pattern for the active elements and hence for the array as a whole. In addition the length of each parasitic element **51***d* to **60***d* and its spacing from its respective dipole can be individually selected in order that the impedance of the dipole-parasite combination on the high-band can be determined substantially independently of the dipole impedance at low-band frequencies. Thus the close-spaced parasites of the embodiment of FIGURES 6 and 7 provide an independent parameter for determination of impedance at high-band frequencies in a manner comparable to that of the capacitors in the embodiment of the antenna array illustrated in FIGURES 1 to 3.

Although they are not essential to the operation of the antenna array, the antenna array **44** is provided with parasitic director elements **62**, **63** and **64**. Parasitic elements **62** and **64** are of the dual-band type and comprise, respectively, conductive segments **62***a*, **62***b*, **62***c* and conductive segments **64***a*, **64***b* and **64***c*. Insulating junctions **62***d* and **62***e* are provided for parasitic element **62** and corresponding insulating junctions **64***d* and **64***e* are provided for parasitic element **64**, so that the segments **62***a*, **62***b*, **62***c* are insulated from one another, as are segments **64***a*, **64***b*, **64***c*. Director **63** is a unitary low-band director. The parasites **62**, **63**, and **64** operate in a substantially conventional manner to increase the directivity and gain of the antenna array, both at high-band and low-band frequencies. Optionally, other forms of parasite may be used.

The present invention is of course not limited to use with the forms of active elements shown with respect to the above described embodiments of the invention. Other types of element and of impedance adjusting means may be employed, suitable to derive the impedance relations described herein below in greater detail. By way of example, an array of simple straight dipoles can be utilized, graduated in length as in FIGS. 6 and 7, or an array of V-dipoles as in FIGURE 1 but at least some utilizing an individual tuning stub or impedance element at its terminals, to determine its desired impedance value.

Alternatively any combination of various types of elements may be utilized, for example longer elements may be of the V-type while shorter elements are straight, the shorter elements having close-spaced parasites or not as preferred.

An important aspect of the invention resides in the impedance relationships which are achieved between the various active elements of the antenna array and particularly those which are achieved at high-band frequencies, as by selection of the capacitance values for the capacitors in the embodiment of FIGURES 1 to 3 or by the characteristics of the close-spaced short parasitic elements in the embodiment of FIGURES 6 and 7, or by other means.

This impedance relationship which contributes substantially to the efficiency of the antenna may be understood by reference to FIGURE 5 and FIGURES 8–11. A schematic diagram of an antenna according to the invention is shown in FIGURE 5 wherein each of the antenna elements **21** to **30** has been replaced by its impedance at a particular frequency represented by boxes labeled $Z_1$ to $Z_{10}$. Returning to the technique of considering the antenna as a transmitting antenna, assume that a television signal, for example a signal of channel 2 frequency is supplied to the input terminals **32**. If the impedance $Z_1$ is very small in value compared to the impedance value looking along the transmission line **31** from the terminals of impedance $Z_1$ to the right in FIGURE 6, then substantially all the unreflected signal will be absorbed in $Z_1$, that is, in antenna element **21**, and all antenna elements farther along transmission line harness **31** will be substantially ineffective. The same is true for the other successive impedances (except the last impedance $Z_{10}$).

On the other hand, if any of the impedances $Z_1$ to $Z_{10}$ were very high in value compared with the impedance of transmission line harness **31**, then that particular antenna element represented by the relatively very high impedance would be relatively ineffective in absorbing energy from the signal.

It is also useful to consider the relative amount of power flow at the junction of any particular impedance which is absorbed by that impedance. It will be understood that the proportion of total entering power which is absorbed by an impedance will be inversely proportional to the value of the impedance relative to the impedance of the remainder of the transmission line viewed from that point. It can also be readily seen that, were the impedance values of all antenna elements equal, then the elements closest to the input terminals **32** would absorb a disproportionately large share of the power. Taking as an example the case where the impedance of each element is such that it absorbs one-half of the power supplied to it, it will be seen that, neglecting reflections, element **21** would absorb one-half the total power, element **22** one-quarter of the total, element **23** only one-eighth, and so on. From the foregoing explanation it will be observed that it is advantageous for the various antenna elements, and particularly those which are most effective at any given frequency, to be arranged so that they have different relative degrees of absorption of impinging power, with greater relative absorption for those effective antenna elements which are farther from the feed point **32**.

According to the invention this relationship of relative absorption of power from the transmission line is maintained for at least several of the antenna elements at all frequencies within the antenna operating frequency range. This can be accomplished throughout the low band by proper selection of element length and is accomplished also in the high band by provision of additional means for independently determining the antenna element

impedance on the high band. The opposite technique of selecting high band impedances by element length and low band impedances otherwise might alternatively be used.

FIGURES 8 to 11 are Smith chart impedance diagrams of certain antenna elements for the extremes of the high and low bands, such as VHF television channels 2, 6, 7 and 13, which illustrate this impedance relationship.

In FIGURES 8 to 11, antenna element complex impedances are plotted on the well known Smith chart curved coordinate system. The impedances plotted are those which would be measured for the particular active antenna element individually and apart from the array as a whole. The impedance plotted is that relative to the transmission line harness characteristic impedance, that is, it is the normalized impedance. In the analysis presented in connection with FIGURES 8 to 11, the transmission line will be considered to be terminated in a matched load for simplicity. Although this is not actually the case the assumption is believed justified in presenting a simple explanation of the basic principles involved.

Impedance coordinates are given by the dashed-line curves in FIGURES 8 to 11, the resistance component of normalized impedance being plotted on the closed circular dashed-line curves **81**, and the reactance component being plotted on the dashed-line curves **83** converging toward the right as indicated by the legends. The complex impedances of three antenna elements have been plotted in each figure. The values plotted actually represent those of the embodiment of the antenna shown in FIGURES 6 and 7, but generally similar values would be found for other embodiments of the invention also. Accordingly the points labeled "Element No. 1" and "Element No. 10" in FIGURES 8 to 11 may be considered to represent the complex impedances of either elements **21** and **30** of the antenna shown in FIGURES 1 to 3 or of elements **51** and **60** of the antenna shown in FIGURES 6 and 7. Intermediate points represent respective intermediate elements.

The solid-line closed circular curves **85** in FIGURES 8 to 11 are the loci of impedance values for which the percentage of impinging power absorbed by an antenna element would have the value as indicated (i.e. 67%, 50%, 33% or 10%).

Considering first FIGURE 8, showing the impedance relations of the antenna array for channel 2, it will be noted that the power absorbed by various antenna elements is greater for element No. **10** farthest from the antenna feed point and generally decreases for elements nearer the feed point.

One of the features of the present invention is that for certain channels some of the antenna elements are effective, while for different channels another group of elements is effective. These various groups which are effective on various channels will generally overlap. In considering which elements are effective at any channel, it should be noted that there are a relatively large number of elements illustratively ten. If all were equally effective, each would have the same induced current as the others, and each would contribute 10% of the total. However, this condition is a theoretical one which could only exist at a single channel, and in fact does not exist on any channel, due to the necessity of design compromise to assure useful action on all channels. In actual practice, the currents in the various elements vary widely from element to element and from channel to channel. If the maximum current for all elements at a single frequency is considered unity, then any element whose current is less than ¼ that maximum contributes so little to operation at that channel as to be relatively ineffective. However, at another channel, such an ineffective element may be highly effective. In FIG. 8, the points **101***a* and **101***b* have been indicated respectively with crossed circles and open circles to indicate the elements of the antenna which are essentially effective at channel 2 and those which are substantially ineffective.

Referring now to FIGURE 9, this figure shows the impedance relationships at channel 6, near the high end of the low-frequency band, at which a small portion of the antenna elements are predominantly effective as indicated by the relatively fewer crossed circle points **102***a*. It will be noted for example that for this channel elements 5 through **10** are relatively ineffective, for the shorter forward antenna elements 1 to 4, however, which are effective, the relationship of greater power absorption for elements farther from the antenna feed point prevails as in the case of channel 2.

The impedance relationships thus far indicated for low-band frequencies can be achieved simply by selection of the length of the active antenna elements. It may be noted that while there are some similarities between the basis of the operation of the antenna and that of antennas disclosed in Schwartz et al. Patent No. 2,817,085 mentioned above, there are also marked dissimilarities between the present antenna and those disclosed in the previous patent. For example, in the present antenna the impedances of the effective elements are highest nearest the front, while in the prior patented antenna, they are highest nearest the rear. Also, the present transmission line harness is transposed instead of straight, and those antenna elements primarily operational at any particular frequency are predominantly capacitively reactive rather than being inductively reactive as were the elements in the antennas disclosed in that patent.

By reference to FIGURES 10 and 11 relating to channel 7 and channel 13 respectively, it will be seen that the individual antenna element impedances at the high band have also been determnied so that the premodinantly effective elements at each frequency are arranged in order of increasing percentage of absorption toward the rear of the antenna as shown by points **103***a*, **103***b*, **104***a* and **104***b*. Particularly those elements near the antenna feed point have the desired absorption relation; this is important to prevent to prevent the middle and rear elements from being ineffective.

Another advantageous aspect of antennas according to the present invention is illustrated in FIGURES 8 to 11. Dot-dash curved lines **105**, **106** are drawn showing normalized impedance values at which the percentage of energy reflected at the antenna element-transmission line junction would be 35% and 12% respectively.

In the discussion of the percentage of absorption previously presented, the absorption figures were given only for that power which was not reflected. Obviously to the extent that there is an impedance mismatch at the junction of the transmission line harness and the antenna element some reflection will take place.

From FIGURES 8 to 11 it will be observed that the percentage of reflection is generally less toward the right of the diagram. The antenna performance will obviously be enhanced if the reflection is minimized, and it is particularly important that there be a relatively low value of reflection for those antenna elements closest to the antenna feed point, for as one approaches the antenna feed point a greater proportion of the total power is subject to reflection. It will be observed in FIGURES 8 to 11 that in all cases element No. 1 is well below the 35% reflection value and in most cases it is below the 12% reflection value. This feature of the antenna provides a good impedance match throughout its operating frequency range and contributes to its superior signal gathering ability.

As illustrations of specific embodiments of the antenna, the dimensions of representative samples of the antennas shown in FIGURES 1 to 3 and in FIGURES 6 and 7 are presented hereinbelow in tabular form.

*Table I.—FIG. 1 Form*

| Elem. No. | Half-Length, inches | Spacing From Rear Adjac. Elem., inches | Forward Tilt Angle, degrees | Capacitor Value, mmf. |
|---|---|---|---|---|
| 1 | 37 | 13 | 30 | 12 |
| 2 | 39¾ | 13 | 30 | 20 |
| 3 | 40½ | 13 | 30 | 25 |
| 4 | 42¾ | 13 | 30 | 30 |
| 5 | 44 | 13 | 30 | ---- |
| 6 | 45¾ | 13 | 30 | ---- |
| 7 | 47¾ | 13 | 30 | ---- |
| 8 | 49 | 13 | 30 | ---- |
| 9 | 50¾ | 13 | 30 | ---- |
| 10 | 53 | ---- | 30 | ---- |

Element diameter—¾".
Element terminals—3 inch spacing.
Harness wire—¼" diameter.

*Table II.—FIG. 7 Form*

| Elem. No. | Length, inches | Spacing From Rear Adjac. Elem., inches |
|---|---|---|
| D-1 | 67½ | 12 |
| D-2 | 60 | 12 |
| D-3 | 67½ | 9 |
| P-1 | 1. | 3 |
| 1 | 45 | 9 |
| P-2 | 20½ | 3 |
| 2 | 50 | 9 |
| P-3 | 22 | 3 |
| 3 | 60 | 8½ |
| P-4 | 23½ | 3½ |
| 4 | 67½ | 8½ |
| P-5 | 25 | 3½ |
| 5 | 73 | 8½ |
| P-6 | 26½ | 3½ |
| 6 | 85 | 8½ |
| P-7 | 28 | 3½ |
| 7 | 87 | 8 |
| P-8 | 29½ | 4 |
| 8 | 94 | 8 |
| P-9 | 31 | 4 |
| 9 | 102¼ | 8 |
| P-10 | 33 | 4 |
| 10 | 110 | ---- |

It will be understood that the foregoing illustrations of specific embodiments of antennas are presented by way of example only and are not intended to be limiting. Numerous variations in the actual construction of this antenna will be apparent to those of skill in the art. For example, active elements of types different than those illustrated may be utilized. However, it is preferred that the active elements be of the type which operate in higher order modes in at least part of the frequency range. It is also somewhat to be preferred that the active elements be of the type which operate in a higher order mode in such a manner as to have greater signal gathering ability than the standard half-wave dipole, that is, that they operate as a longer-than-half-wave dipole or as a set of colinear half-wave dipoles, so as to have positive gain. This enhances the high-band efficiency of the dipoles of the antenna arrays disclosed in FIGURES 1 to 3 and 6 to 7. The positive element gain of the elements of the illustrated antennas in the high order mode makes them superior to previous high band end-fire antennas and they are accordingly adaptable for use even where no low order mode (half-wave) operation is contemplated. In such case the antenna parameters may be optimized for solely high band or high order mode operation.

Antennas according to the present invention may also be varied or modified by changing the type of interconnecting transmission line to other than an air-dielectric two-wire transmission line or by varying the physical dimensions such as spacing between elements, element lengths, transmission line wire spacing and the like so long as the electrical characteristics conform to those described and claimed as within the scope of the invention.

It will also be apparent that parasitic elements could be added to the embodiment shown in FIGURES 1 to 3 or that different parasitic elements could be utilized in conjunction with the embodiment illustrated in FIGURES 6 and 7, or alternatively the parasitic elements could be dispensed with. Further active elements could also be added, for example in front of the feed point, and such elements need not utilize a transposed transmission line harness.

While the present invention has been specifically described with respect to the two-band VHF television broadcasting, the principles of the invention are useful whenever extremely wide frequency ranges are used of the order of 3 to 1 or more, and is particularly not limited to harmonically related frequency bands.

Numerous other variations will be apparent to those of skill in the art in addition to those described or suggested and it is accordingly desired that the scope of the invention not be restricted to those embodiments shown or suggested but that it shall be limited solely by the scope of the appended claims.

Certain theories of operation of antennas according to the present invention have been set forth which are believed to be correct, but the scope of the invention is in no way intended to be limited by the theory of operation described, and the operability of the antenna is based upon performance of the actual embodiments presented by way of example and not upon theoretical considerations.

What is claimed is:

1. A broad-band directive antenna array having a direction of greater effectiveness extending from its front end comprising at least six dipole elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole elements disposed in a common plane and at least six adjacent ones of said elements being of graduated length decreasing toward the front of said array, means for connecting a signal transmission line to the front one of said elements, means for connecting each other dipole element of said array to the dipole element forward thereof, the last said means comprising an air-dielectric transmission line harness with the conductors thereof transposed to connect respectively to opposite terminals of each pair of adjacent dipole elements which it interconnects, said harness having a length between respective elements substantially equal to the inter-element spacing, said dipole elements having different respective impedances relative to the impedance of said transmission line harness at their respective points of connection thereto, said element relative impedances increasing toward the front of said array and causing the proportion of energy absorbed from the transmission line harness by respective dipole elements to be progressively greater for elements farther from said transmission line connecting means, the said absorption relationship obtaining for any set of three adjacent elements at at least one operating frequency within the operating range of said array, and means for determining the harmonic mode radiation pattern and impedance of certain of said elements comprising close spaced short parasitic elements in front of certain of said dipole elements, said parasitic elements causing the said absorption relationship to obtain for at least three adjacent dipole elements of said array throughout said operating range of frequencies, including a portion of said range where said elements function in a harmonic mode.

2. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising at least three active dipole antenna elements arrayed in file in horizontally spaced relation, means for causing said active elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three to one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, signal transmission means electrically connected to said

active elements for coupling said array to other apparatus, said signal transmission means comprising (*a*) means for connecting a signal transmission line to one of said active elements in front of the rear one of said active elements and (*b*) a harness transmission line means interconnecting said one active element and at least two of said other active elements, said harness means having a line transposition between said one active element and its rearwardly adjacent active element.

3. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising a group of at least three adjacent active dipole antenna elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole antenna elements disposed in a common substantially horizontal plane, said elements being of graduated length decreasing toward the front of said array, means for causing said antenna elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three to one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, means for connecting a signal transmission line to the front one of said elements, harness means for electrically connecting each other antenna element of said group to the antenna element forward thereof, the last said means comprising a transmission line harness having a line transposition between each pair of adjacent antenna elements of said group, said harness having a length between adjacent ones of said elements substantially equal to the spacing between said adjacent elements.

4. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising at least three active dipole antenna elements arrayed in file in horizontally spaced relation, means for causing said active elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three to one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, signal transmission means electrically connected to said active elements for coupling said array to other apparatus, said signal transmission means comprising (*a*) means for connecting a signal transmission line to one of said active elements in front of the rear one of said active elements and (*b*) a harness transmission line means interconnecting said one active element and at least two of said other elements, said harness means having a line transposition between said one active element and its rearwardly adjacent active element, at each channel in the operating range of said array one group of elements at least three in number having a set of relative impedances related to the characteristic impedances of the harness means connected immediately forwardly thereof, said set of relative impedances decreasing progressively in a rearward direction.

5. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising a group of at least three adjacent active dipole antenna elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole antenna elements disposed in a common substantially horizontal plane, said elements being of graduated length decreasing toward the front of said array, means for causing said antenna elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three to one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, means for connecting a signal transmission line to the front one of said elements, harness means for electrically connecting each other antenna element of said group to



the antenna element forward thereof, the last said means comprising a transmission line harness having a line transposition between each pair of adjacent antenna elements of said group, said harness having a length between adjacent ones of said elements substantially equal to the spacing between said adjacent elements, at each channel in the operating range of said array one group of elements at least three in number having a set of relative impedances related to the characteristic impedances of the harness means connected immediately forwardly thereof, said set of relative impedances decreasing progressively in a rearward direction.

6. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising at least three active dipole antenna elements arrayed in file in horizontally spaced relation, the least interelement spacing between any two of said elements differing not more than 20% from the greatest interelement spacing between any adjacent two of said elements, means for causing said active elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three-to-one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, signal transmission means electrically connected to said active elements for coupling said array to other apparatus, said signal transmission means comprising (*a*) means for connecting a signal transmission line to one of said active elements in front of the rear one of said active elements and (*b*) a harness transmission line means interconnecting said one active element and at least two of said other active elements, said harness means having a line transposition between said one active element and its rearwardly adjacent active element.

7. A dual-band directive antenna array having a direction of geater effectiveness extending from its front end comprising at least three active dipole antenna elements arrayed in file in horizontally spaced relation, with each interelement spacing not greater than substantially one-quarter wave-length at the highest operating frequency of said array, means for causing said active elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three-to-one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, signal transmission means electrically connected to said active elements for coupling said array to other apparatus, said signal transmission means comprising (*a*) means for connecting a signal transmission line to one of said active elements in front of the rear one of said active elements and (*b*) a harness transmission line means interconnecting said one active element and at least two of said other active elements, said harness means having a line transposition between said one active element and its rearwardly adjacent active element.

8. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising a group of at least three adjacent active dipole antenna elements arrayed in file in horizontally spaced relation with corresponding arms of said dipole antenna elements disposed in a common substantially horizontal plane, said elements being of graduated length decreasing toward the front of said array, means for causing said antenna elements individually to have similarly oriented directivity characteristics at each of the two operating frequencies having a frequency ratio of substantially three-to-one, said means comprising a close spaced conductive rod element substantially parallel to and in front of each of said dipole antenna elements and having a length not more than half that of its corresponding dipole antenna element, means for connecting a signal transmission line to the front one of said elements, harness means for electrically connecting each other antenna element of said

group to the antenna element forward thereof, the last said means comprising a transmission line harness having a line transposition between each pair of adjacent antenna elements of said group.

9. A dual-band directive antenna array having a direction of greater effectiveness extending from its front end comprising at least three active dipole antenna elements arrayed in file in horizontally spaced relation, with each interelement spacing not greater than substantially one-quarter wave-length at the highest operating frequency of said array and with the least interelement spacing between any two of said elements differing not more than 20% from the greatest interelement spacing between any adjacent two of said elements, means for causing said active elements individually to have similarly oriented directivity characteristics at each of two operating frequencies having a frequency ratio of substantially three-to-one, said means comprising a close spaced short parasitic element substantially parallel to and in front of each of said dipole antenna elements, signal transmission means electrically connected to said active elements for coupling



said array to other apparatus, said signal transmission means comprising (*a*) means for connecting a signal transmission line to one of said active elements in front of the rear one of said active elements and (*b*) a harness transmission line means interconnecting said one active element and at least two of said other active elements, said harness means having a line transposition between said one active element and its rearwardly adjacent active element.

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# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,086,206 April 16, 1963

Harry Greenberg

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, lines 31 and 32, for "otherwire" read -- otherwise --; column 9, line 48, for "greater" read -- greatest --; column 10, line 35, for "determnied" read -- determined --; line 41, strike out "to prevent", first occurrence.

Signed and sealed this 29th day of October 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWIN L. REYNOLDS
Acting Commissioner of Patents

JFD EXHIBIT 2B.

Oct. 22, 1963 P. E. MAYES ETAL 3,108,280

LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

Filed Sept. 30, 1960 2 Sheets-Sheet 1

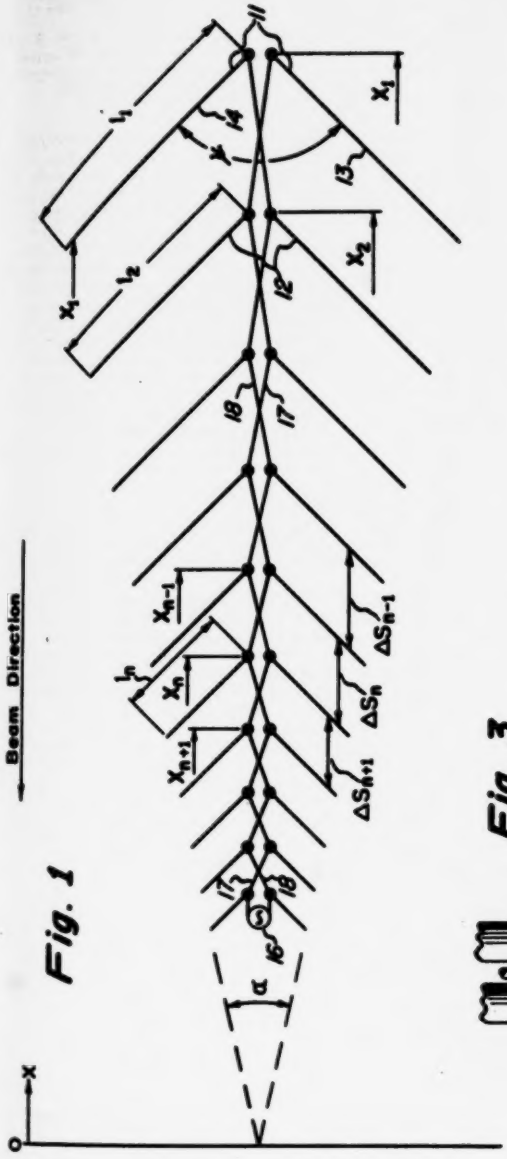
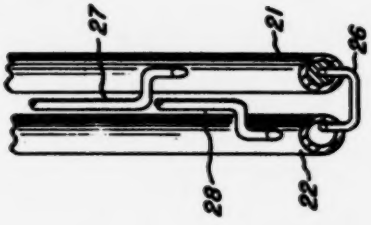



Fig. 1

Fig. 3

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Merriam, Smith & Marshall
ATTORNEYS

Oct. 22, 1963 P. E. MAYES ETAL 3,108,280

LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

Filed Sept. 30, 1960 2 Sheets-Sheet 1

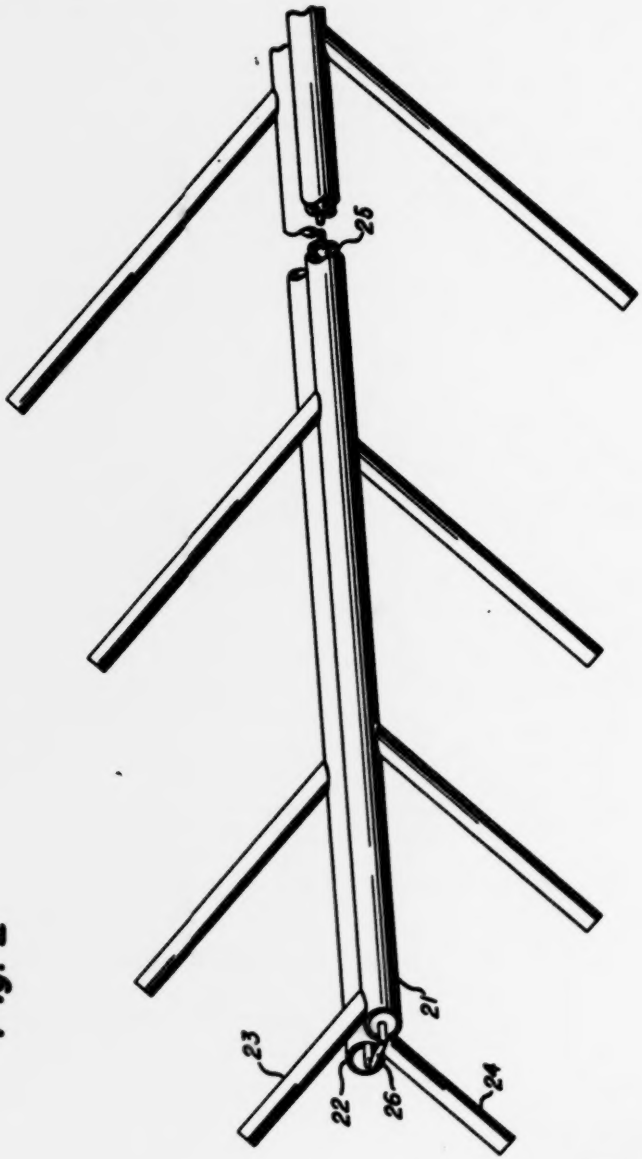


Fig. 2

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United States Patent Office

3,108,280

Patented Oct. 22, 1963

1

RE. 25,740 March 9, 1965
3,108,280

# LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

Paul E. Mayes, Champaign, and Robert L. Carrel, Urbana, Ill., assignors to The University of Illinois Foundation, a non-profit organization of Illinois

Filed Sept. 30, 1960, Ser. No. 59,671
10 Claims. (Cl. 343—792.5)

This invention relates to antennas and more particularly it relates to antennas having unidirectional radiation patterns that are essentially independent of frequency over wide bandwidths.

In the copending application of Dwight E. Isbell, Ser. No. 26,589, filed May 3, 1960, there are described certain antennas comprising coplanar dipole arrays which have an unusually wide bandwidth over which the performance of the antennas is essentially frequency independent and the input impedance nearly constant, the antennas also having a unidirectional pattern with a directivity comparable to a Yagi array. As described in the aforementioned application, these arrays comprise a number of dipoles arranged in side-by-side relationship in a plane, the length of the dipoles and the spacing between adjacent dipoles varying according to a definite mathematical formula, with each of the dipoles being fed at its midpoint by a common feeder which introduces an added phase shift of 180° between connections to successive dipoles. The dipoles which are used to make up the array vary progressively in length, the longest dipole element being about ½ wavelength long at the low frequency limit of a given antenna's effective range and the shortest element being about ⅜ wavelength long at the upper frequency limit.

In accordance with the present invention, it has been found that the directivity of an antenna of the type described in the aforementioned application may be increased and the effective frequency range of an antenna of fixed size may be extended by inclining the dipoles of Isbell to form V-elements, each of which consists of two straight arms of equal length defining an apex which points away from the direction of radiation of the antenna which is also the direction in which the element size decreases. The modification of the straight dipoles of Isbell to V-shaped elements permits the antenna to be operated over bands of frequencies higher than those established, as described above, by the length of the shortest dipole in the antenna, with increased directivity, thus obviously increasing the effective frequency range of a given antenna.

The invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying drawings, in which the same numbers are used to denote corresponding elements in the several views and in which:

FIGURE 1 is a schematic plan view of an antenna made in accordance with the principles of the invention;

FIGURE 2 is a perspective view of a practical antenna embodying the invention; and

FIGURE 3 is a fragmentary view of an improved and preferred form of an antenna similar to that shown in FIGURE 2, as seen from a point directly in front of and above the narrow end of the antenna.

Referring to FIGURE 1, it will be seen that the antennas of the invention are composed of a plurality of V-elements, e.g., 11 and 12, each of which consists of a pair of arms, e.g., 13 and 14, defining an apex in the middle of the V-elements, said V-elements being arranged in a herringbonelike pattern. The arms of a given V-element are equal in length and corresponding arms of the several V-elements, i.e., the arms on the same side of a line passing through the apexes of the V-elements, are

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substantially parallel to each other. It will be noted that the lengths of the arms of successive V-elements and the spacing between the apexes of the elements are such that the extremities of the elements fall on a pair of straight lines which intersect to form an angle $\alpha$. In the preferred embodiment of the invention the antenna is symmetrical about a line passing through the apexes of the V-elements, as shown.

The antenna is fed at its narrow end from a conventional source of energy, depicted in FIGURE 1 by alternator 16, by means of a balanced feeder line consisting of conductors 17 and 18. It will be seen that the feeder lines 17 and 18 are alternated between connections to consecutive V-elements, thereby producing a phase reversal between such connections.

The lengths of the arms in the antenna, and the spacing between the V-elements, are related by a constant scale factor $\tau$ defined by the following equations:

$$\tau = \frac{l_{(n+1)}}{l_n} = \frac{\Delta S_{(n+1)}}{\Delta S_n}$$

where $\tau$ is a constant having a value less than 1, $l_n$ is the length of an arm in any intermediate V-element in the array, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element, the subscript $n$ designating the $n$th arm running in an order from larger to smaller, $\Delta S_n$ is the spacing between the apex of the V-element having the arm length $l_n$ and the apex of the adjacent larger V-element, and $\Delta S_{(n+1)}$ is the spacing between the apex of the V-element having the arm length $l_n$ and the apex of the adjacent smaller V-element.

The arms of the individual V-elements forming the antenna array are inclined to point in the direction of decreasing V-element size so that the apex of each of the elements points in a direction away from the angle $\alpha$ formed by the lines passing through the extremities of the individual V-elements.

The angle formed by the arms of a V-element is designated as $\psi$. It will be seen that when the angle $\psi$ is equal to 180°, the antennas of the invention are identical with those described by Isbell in the application mentioned above. In the instant invention, however, the angle $\psi$ preferably has a value between about 50° and 150°.

It will be seen from the geometry of the invention as given above that the distances from the base line O at the vertex of the angle $\alpha$ to the apexes of the V-elements forming the array are defined by the equation:

$$\tau = \frac{X_{(n+1)}}{X_n}$$

where $X_n$ is the distance from the base line O to the apex of the V-element having the arm length $l_n$, $X_{(n+1)}$ is the corresponding distance from the base line to the apex of the adjacent smaller V-element, the $\tau$ has the significance previously given.

The radiation pattern of the antennas of the invention having the geometrical relationship among the several parts, as defined above, is unidirectional in the negative X direction, i.e., extending to the left from the narrow end of the antenna of FIGURE 1.

The use of V-elements in the antennas of the invention, rather than dipoles, increases the directivity of the invention and also permits more effective utilization of a given antenna since the same structure can be used in several frequency modes to achieve coverage of different frequency bands. In the special case of an antenna having straight dipoles rather than V-elements (i.e., when $\psi = 180°$), the effective frequency range is that in which the low limit corresponds to that frequency in which the largest dipole in the antenna is about ½ wavelength long and the upper frequency limit to that frequency in which the smallest dipole in the antenna is about ⅜ wavelength

long. In general, therefore, it may be said that the frequency range of the straight dipole array corresponds to the mode of operation in which the lengths of the dipoles in the array are about ½ wavelength long. As the frequency is raised above the upper limit of the ½ wavelength mode in the dipole array, the antenna will also be found to radiate effectively at frequencies in which the dipoles are about ⅔ wavelengths long (the ⅔ wavelengths mode), ⅝ wavelengths long (the ⅝ wavelengths mode) and so on. At frequencies above the half-wavelength mode, however, the radiation pattern of the dipole array becomes multilobed and is, therefore, of limited usefulness. By including the arms of the dipole to form the V-elements of the instant invention, it has been found that a single lobe of improved directivity may be obtained as the frequency is raised from the half-wavelength mode through the intervening ranges to the ⅝ wavelengths mode and beyond. For each mode of operation there exists an optimum value for the angle $\psi$, ranging from about 114° for the half-wavelength mode to about 62° for the ⅝ wavelengths mode. By using a compromise value for $\psi$ within this range, however, a practical antenna can be made to achieve acceptable performance over several modes of operation, thereby increasing its effective range without increasing the number of elements therein. This result is possible since many of the elements forming the antenna array are used at more than one frequency.

The construction of an actual antenna made in accordance with the invention is shown in FIGURE 2. In this antenna the balanced line consists of two closely-spaced and parallel electrically conducting small diameter tubes **21** and **22** which also act as a mechanical support for the dipole elements and to which are attached the arms which form the V-elements of the invention. It will be noted that each of the two arms, e.g., **23** and **24**, making up one V-element is connected to a different one of said conductors **21** and **22**. Moreover, considering either one of the conductors **21** and **22**, consecutive arms along the length thereof extend in opposite directions. It will be seen that this construction has the effect of alternating the phase of the connections between successive V-elements, as depicted schematically in FIGURE 1. Although the V-elements of FIGURE 2 are not precisely coplanar, differing therefrom by the distance between the parallel conductors **21** and **22**, in practice this distance is usually small so that the arms of the V-elements are substantially coplanar and the advantages of the invention are maintained. In some instances, however, it may be advantageous to bend the individual arms, e.g., **27** and **28**, close to the point of attachment to the feeder line, as shown in FIGURE 3, so as to position all the arms in the same plane. The antennas of FIGURES 2 and 3 may be conveniently fed by means of a coaxial cable **25** positioned within conductor **21**, the outer conductor of the cable making electrical contact with conductor **21** and the central conductor **26** of the cable extending to and making electrical connection with conductor **22**, as shown.

The antennas of the invention may also be fed by a balanced two wire line which is twisted between elements to achieve the desired phase reversal. Other methods of achieving the desired phasing may be employed, e.g., transmission line loops or stubs.

As an example of the invention, an antenna of the type shown in FIGURE 3 was constructed using 0.125" diameter tubing for the balanced line and 0.050" diameter wire for the arms of the V-elements. The arms were soldered to the feeder line and the array was fed by a miniature coaxial cable inserted into one of the conductors of the balanced line. The antenna had 25 arms, the largest of which was 1 ft. long with the shortest being about 3½" long. The antenna was further defined by the parameters $\tau = 0.95$ and $\psi = 70°$. This antenna exhibited typical directivity gains ranging from 12 db over isotropic in the ⅔ wavelengths mode to 17 db in the ⅞ wavelengths mode, with essentially constant input impedance within each mode.

Except with respect to the angle of inclination of the arms of the V-elements, the parameters which define the antennas of the invention are essentially similar to those of the corresponding straight dipole arrays in which the arms extend at right angles from the feeder lines. Thus the parameter $\tau$ preferably has a value between about 0.8 and 0.95 and the angle $\alpha$ suitably ranges between 20° and 100°. Moreover, the upper and lower limits of the bandwidth for the ½ wavelength mode of operation can be adjusted as desired by making the longest V-element correspond in length to about ½ wavelength at the lower limit and the shortest V-element to about ⅜ wavelength at the upper frequency limit.

In addition to its use as a direct radiator or receiver, the resonant-V array of the invention has several advantages over other antennas currently used as primary feeds for parabolic and other reflectors. Its independence of frequency in any single mode assures constant illumination of the reflector. Moreover, the input impedance remains essentially independent of frequency so that no tuning is required as the frequency is varied.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A broadband unidirectional antenna comprising an array of a plurality of V-elements in a planar herringbonelike arrangement, each of said elements having a pair of equal arms defining an apex, the apexes of said V-elements lying on a straight line, the corresponding arms of said elements progressively increasing in length and spacing, the extremities of the arms of said V-elements substantially falling on a V-shaped line forming an angle $\alpha$ at its vertex, the apexes of said V-elements pointing in a direction away from the vertex of said angle $\alpha$, the ratio of the arm lengths of any pair of adjacent V-elements being given by the formula

$$\frac{l_{(n+1)}}{l_n} = \tau$$

where $l_n$ is the length of an arm in the larger of said pair of V-elements, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element of said pair, the subscript $n$ designating the $n$th arm running in an order from larger to smaller, and $\tau$ is a constant having a value less than 1, the spacing between the apexes of said V-elements being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n} = \tau$$

where $\Delta S_n$ is the spacing between the V-element having the arm length $l_n$ and the adjacent larger V-element, $\Delta S_{(n+1)}$ is the spacing between the V-element having the arm length $l_n$ and the adjacent smaller V-element, and $\tau$ has the significance previously assigned, said V-elements being adapted to be fed as a group from the small end of the individual V-elements fed at the apexes thereof by a common feeder which introduces an additional 180° phase shift between successive V-elements.

2. The antenna of claim 1 wherein the angle formed by the arms of any V-element at the apex thereof has a value within the range from about 50° to about 150°.

3. The antenna of claim 1 which is symmetrical about a line passing through the apex of each V-element therein, and in which the corresponding arms of the V-elements are parallel.

4. The antenna of claim 1 in which the angle $\alpha$ has a value between about 20° and 100° and the constant $\tau$ has a value between about 0.8 and 0.95.

5. A broadband unidirectional antenna comprising a balanced feeder line consisting of two closely spaced, straight and parallel conductors, a plurality of substan-

tially coplanar V-elements, each V-element comprising a pair of arms of equal length defining an apex, one of said arms of each V-element being connected at the apex of said V-element to one of said conductors, the other of said arms being connected directly opposite the first to the other of said conductors, the arms of any V-element extending in opposite directions at an acute angle to the plane determined by said conductors, consecutive arms on each of said conductors extending on opposite sides of said plane, the ratio of the lengths of the arms in adjacent V-elements being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an arm of a V-element, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element, the subscript $n$ designating the $n$th arm running in an order from larger to smaller, and $\tau$ is a constant having a value less than 1, the spacing of the apexes of the V-elements along said feeder line being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the V-element having the arm length $l_n$ and the adjacent larger V-element, $\Delta S_{(n+1)}$ is the spacing between the V-element having the arm length $l_n$ and the adjacent smaller V-element, and $\tau$ has the significance previously assigned.

6. The antenna of claim 5 in which the angle formed by said arms with the plane determined by said feeder line, measured in a plane perpendicular to said plane, has a value between about 25° and about 75°.

7. The antenna of claim 5 in which $\tau$ has a value of about 0.8 to 0.95.

8. An aerial system for wide-band use comprising a plurality of herringbone-like conducting V-elements planarly arranged, a two-conductor balanced feeder connected to each of said elements at substantially the inner end thereof, each two opposite V-elements forming a pair constituting dipole halves, the connection from each adjacent dipole section being to a different feeder, said V-elements being selectively spaced from each other, each V-element of each pair having arms of substantially equal length substantially defining an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and terminating at the feeder, the said dipoles of each pair being of different electrical lengths with successive dipoles differing in electrical length with respect to each other by substantially the same scale factor, each dipole and the feeder between successive dipoles constituting a cell, and the selective spacings between adjacent dipoles decreasing from one end to the other with the greater spacing being between the longest dipoles and being such that the combination of dipole lengths and spacings provides a substantially uniform wide-band response over a plurality of frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the dipoles and the feeder being made in such a manner that the directive gain of the antenna increases as operation shifts from one band to an adjacent band of higher frequencies, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements and in the direction of the smallest of the V-elements.

9. An aerial system for wide-band use including a two-conductor balanced feeder extending in a selected plane, a plurality of herringbone-like conducting V-elements planarly arranged and spaced along the feeder, each of the elements having a pair of arms of substantially equal length defining substantially an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and all terminating at the feeder, a connection between each of the V-elements and one of the feeders at the inner end of the elements, the two V-elements forming each pair constituting dipole halves, adjacent dipole sections being connected to different feeders, each of the pairs of dipoles being of different electrical lengths with successive dipoles differing in electrical length with respect to each other by substantially a common scale factor, each dipole and the feeder connected thereto in the region between one dipole pair and the next adjacent dipole pair constituting a cell, the spacings between the dipoles as connected to the feeders differing from each other also by substantially the same common scale factor, the scale factor being so chosen that the combination of dipole lengths and spacings providing the several cells have a substantially uniform wide-band response over several frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the feeder and the dipoles being made in such a manner that the directive gain of the antenna increases with operational shift from one band to another band of higher frequency, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements in the direction of the smallest of the V-elements.

10. An aerial system for wide-band use including an elongated two-conductor balanced feeder, a plurality of herringbone-like conducting V-elements planarly arranged and spaced along said feeder, each of the elements having a pair of arms of equal length defining substantially an apex with the apexes of the plurality of V-elements all lying in a substantially straight line, a connection between each of the V-elements and the feeder to terminate the elements substantially at the feeder, the two V-elements forming each pair constituting dipole halves, adjacent dipole sections of the plurality being connected to different feeders and the dipoles being relatively spaced so that the spacings between successive dipoles differ from each other by substantially a common scale factor, adjacent dipole sections having different electrical lengths, each dipole and the feeder connected between it and the adjacent dipole constituting a cell, the lengths of the dipoles increasing from end of array where spacings between adjacent dipoles is less to end of the array where adjacent dipoles are spaced the greatest distance, the spacings by the scale factor variation between adjacent dipoles being such that a combination of the various dipole lengths and spacings provides a substantially uniform wide-band response over several frequency bands bearing substantially harmonic frequency relationships to each other, the connection being made in such a manner that the directive gain of the antenna increases as the operation shifts from one band to another band of higher frequency, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements in the direction of the smallest of the V-elements.

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7 8

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,108,280 October 22, 1963

Paul E. Mayes et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 13, for "including" read -- inclining --.

Signed and sealed this 26th day of May 1964.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

JFD EXHIBIT 2C.

May 26, 1964 R. L. BELL 3,134,979

TAPERED LADDER LOG PERIODIC ANTENNA

Filed Jan. 27, 1961 3 Sheets-Sheet 1

FIG. 1b
PRIOR ART

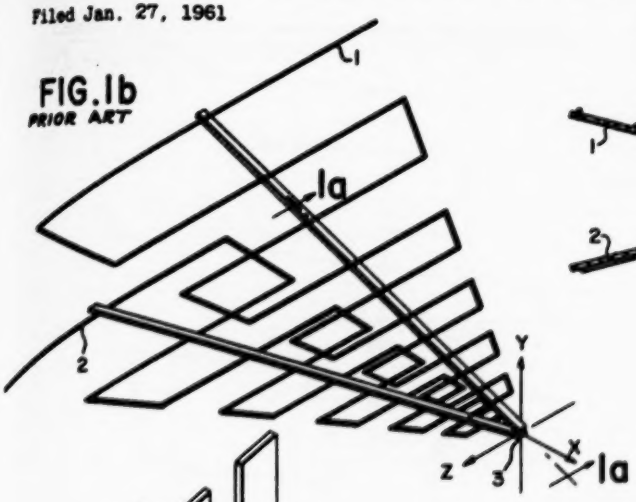


FIG. 1a
PRIOR ART

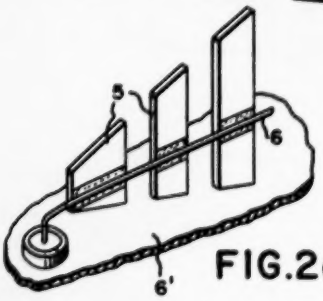


FIG. 2a

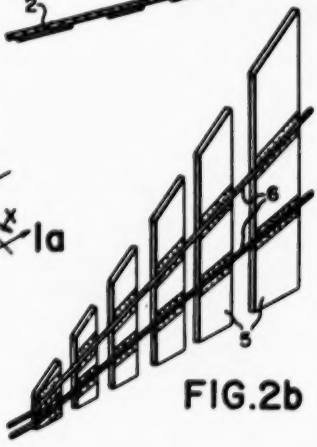


FIG. 2b

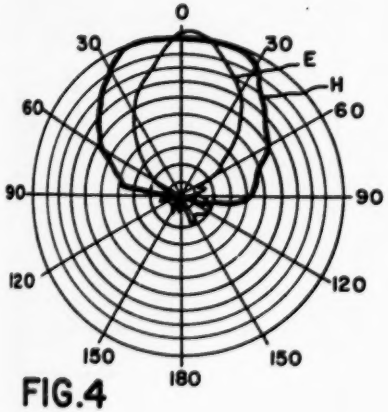


FIG. 4

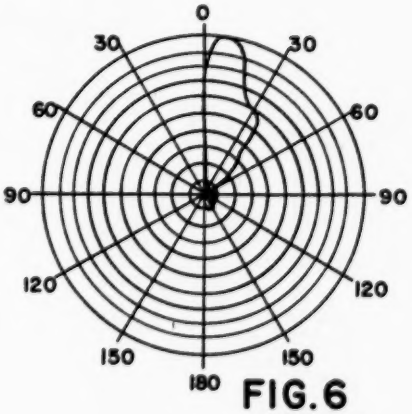


FIG. 6

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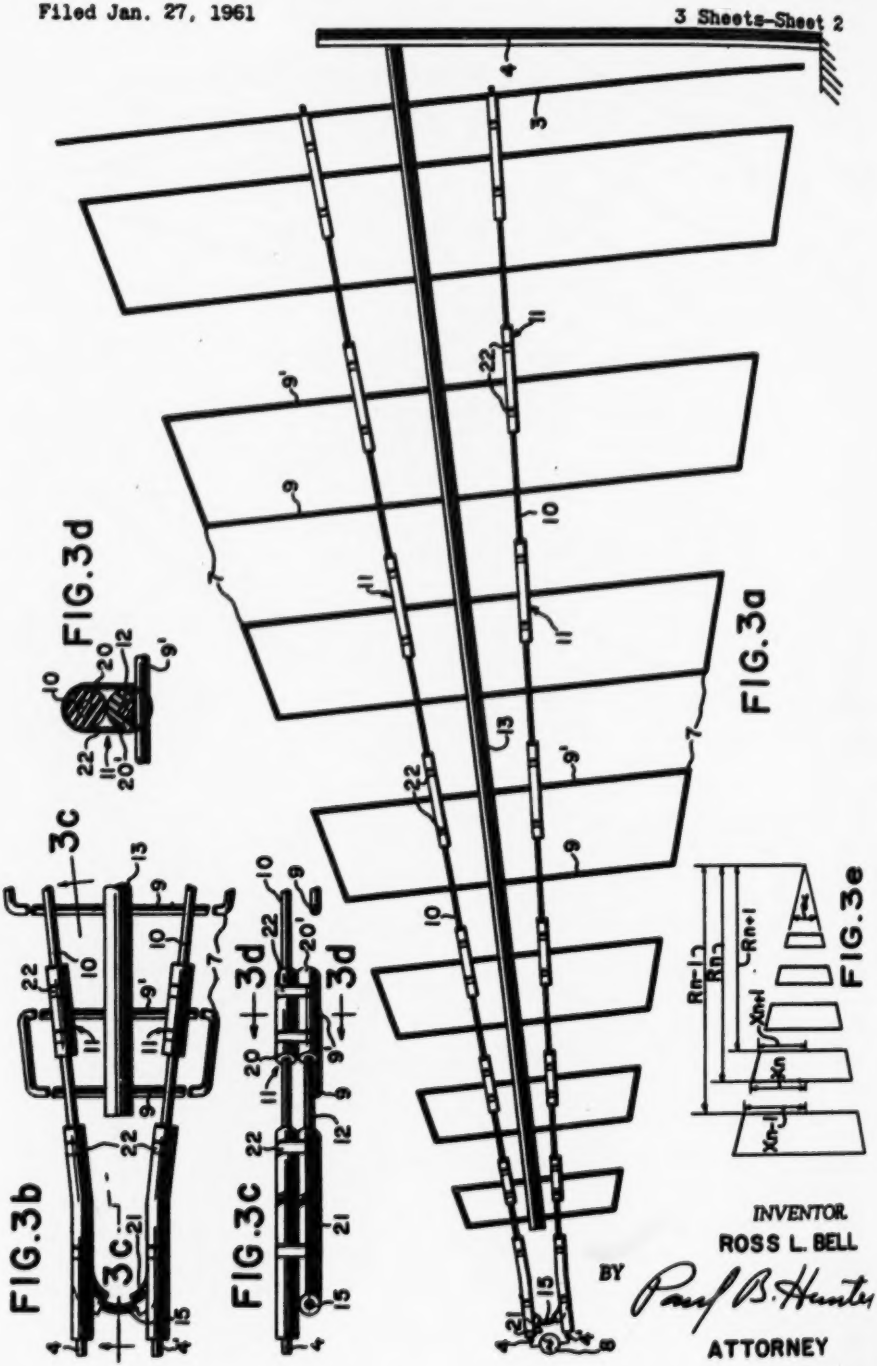
May 26, 1964 R. L. BELL 3,134,979

TAPERED LADDER LOG PERIODIC ANTENNA

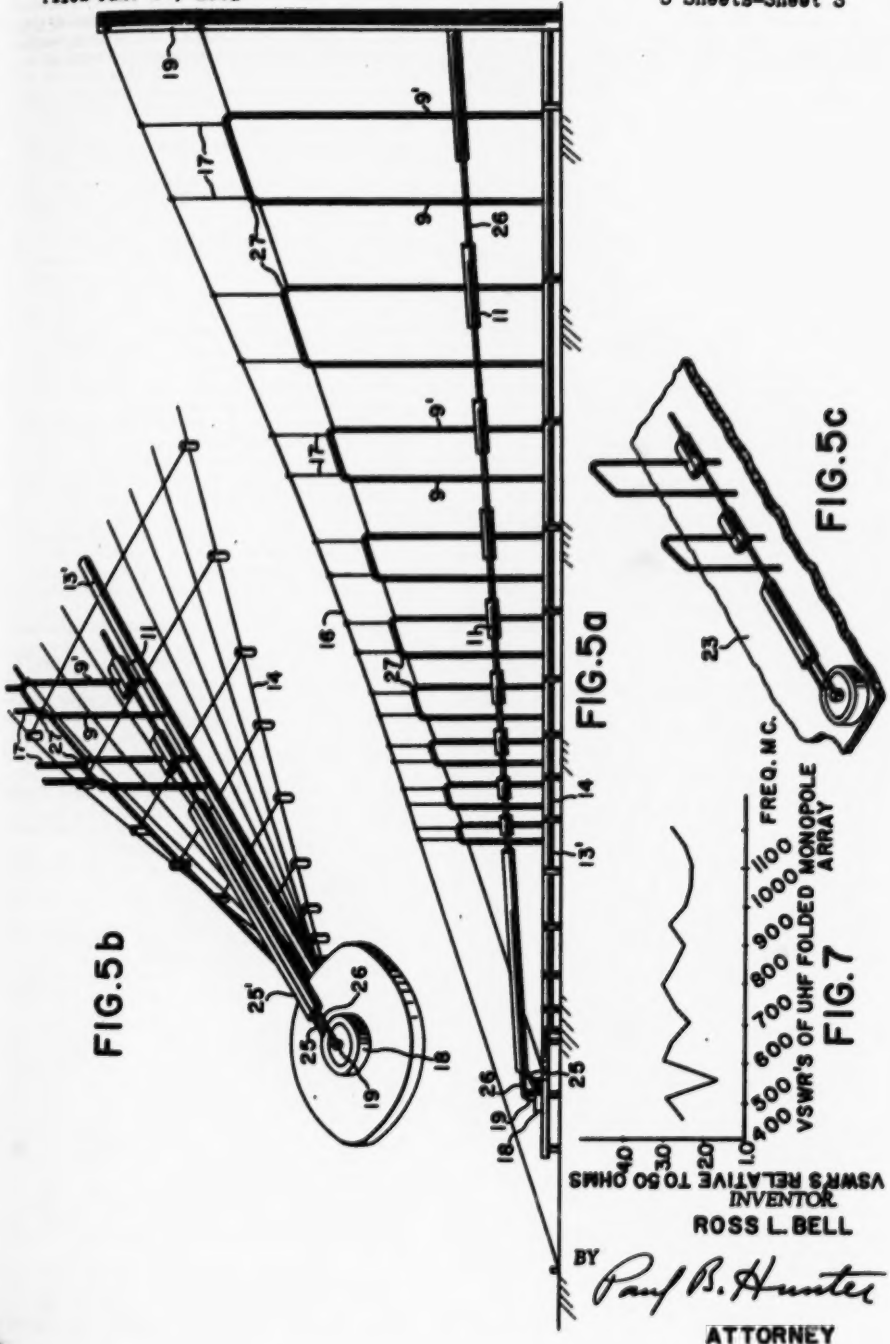
Filed Jan. 27, 1961 3 Sheets-Sheet 2



May 26, 1964 R. L. BELL 3,134,979

TAPERED LADDER LOG PERIODIC ANTENNA

Filed Jan. 27, 1961 3 Sheets-Sheet 3



United States Patent Office 3,134,979 Patented May 26, 1964



3,134,979

# TAPERED LADDER LOG PERIODIC ANTENNA

Ross L. Bell, San Jose, Calif., assignor to Granger Associates, Palo Alto, Calif., a corporation of California

Filed Jan. 27, 1961, Ser. No. 85,233
4 Claims. (Cl. 343—792.5)

This invention relates generally to antenna structures, and the invention relates more particularly to a novel symmetrical antenna of the log-periodic type.

Log-periodic antennae have been developed within the last few years which have the desirable properties of maintaining relatively constant radiation patterns and impedances over relatively large frequency bands of the order of 10:1 or even greater. While these antennae perform satisfactorily for many applications they are not compatible with systems operating in the high frequency range that require vertical polarization. In addition, the physical configuration of these log-periodic antennae as heretofore constructed leave much to be desired, both from the structural and fabrication points of view.

The early unidirectional log-periodic antennae usually consisted of two separate planar antennae that diverged from the apex or feedpoint with repetitious antenna elements whose dimensions increase with increasing distance from the apex of the array. These antennae occupied a considerable volume, thereby producing complex structural problems which are magnified when the antennae are to be operated in environments which have even moderate wind and icing conditions. In addition, the structures are asymmetrical, that is, the portion above the X—Z plane is not a mirror image of the portion below this plane, and this makes it impossible for imaging these antennae as over the ground or over a counterpoise. Thus, for vertical polarized applications these prior art antennae have been restricted to optimum performance only in a free space environment. Furthermore, the asymmetrical structure makes these antennae in use difficult to maintain due to differential wind pressures on the two planar members or arms of the antenna.

More recently a balanced or symmetrical form of log-periodic antenna, known as the "tapered ladder" has been developed jointly by the applicant hereof and Arthur F. Wickersham, Jr. consisting of tapered plates of progressively larger dimension as measured from the apex and are shunt-excited as by leads. While the radiation patterns and impedances of the tapered ladder antenna are very satisfactory, in practice, however, its usefulness is limited to frequencies of relative short wavelengths due to the fact that the radiating elements are solid plates which render the "tapered ladder" extremely vulnerable to wind loading as well as extremely expensive at lower frequencies.

It is a principal object of the present invention to provide a novel antenna of the log-periodic type which is of simple construction and has highly desirable structural features, i.e., which is of relative light weight, rugged, and can withstand large wind loading, and which may be used for space radiation or may be imaged over the ground or counterpoise, resulting in such case in a substantial reduction in the antenna height for the same range of operating frequency.

A feature of the present invention is to provide a novel, simply constructed symmetrical log-periodic antenna that comprises, in effect, a series of folded dipole radiators that diverge from an apex and in which the pertinent dimensions of the radiators increase uniformly and proportionally with an increase in distance from the apex of the structure.

Still another feature of the present invention is to provide a novel symmetrical broadband antenna employing



rod or wire antenna elements in trapezoidal form and which is capable of having an exceptionally wide frequency band and wherein the dipole elements are shunt excited.

Another feature of the present invention is to provide an antenna of the above character wherein energy from the antenna terminals when acting as a transmitter travels along a balanced two-wire transmission line toward the rear or large end of the structure until it reaches the active region, that being the one in which the folded dipole elements are near resonance wavelength at the operating frequency.

Still another feature of the present invention is to provide a novel antenna that is well adapted to be used as a folded monopole array operating in conjunction with the ground or counterpoise.

These and other features and advantages of the present invention will be more apparent after a perusal of the following specification taken in connection with the accompanying drawings wherein:

FIG. 1*a* shows a sectional view through a prior art asymmetrical log-periodic antenna,

FIG. 1*b* is a perspective view which shows the antenna of FIG. 1*a* with the planar members 1 and 2 extending above and below the X—Z plane,

FIG. 2*a* is a perspective view which shows a tapered ladder antenna suitable for being mirrored or vertically imaged,

FIG. 2*b* is a perspective view which shows a tapered ladder antenna useful for free space environment,

FIG. 3*a* is a perspective view of the novel folded dipole antenna of this invention suitable for free space environment,

FIG. 3*b* is an enlarged fragmentary view of a portion of the structure shown in FIG. 3*a*,

FIG. 3*c* is an enlarged sectional view taken along line *c*—*c* of FIG. 3*b* looking in the direction of the arrows,

FIG. 3*d* is an enlarged sectional view taken along the line *d*—*d* of FIG. 3*c* looking in the direction of the arrows,

FIG. 3*e* illustrates the geometry of the structure of FIG. 3*a* in plan,

FIG. 4 is a typical E- and H-plane pattern of the novel antenna structure of FIG. 3*a*,

FIG. 5*a* shows in elevation an imaged, folded monopole array embodying the present invention,

FIG. 5*b* is a perspective view of a portion of the structure shown in FIG. 5*a*,

FIG. 5*c* is a perspective fragmentary view of a monopole array employing a ground plane,

FIG. 6 illustrates a typical elevational pattern for the folded monoplane antenna of FIG. 5*a*; and

FIG. 7 shows the VSWR's of the antenna structure of FIGS. 5*a* and 5*b* with respect to a nominal impedance of 50 ohms.

Referring now to the drawings, FIGS. 1*a* and 1*b* show an early form of periodic antenna having two asymmetrical periodic plane members 1 and 2 that diverge from the apex or feedpoint 3, the said planar members being separated by an angle $\psi$ as shown in FIG. 1*a*. Antennae of this nature occupy considerable volume, producing complex structural problems which are magnified when the antennae are operated in environments having even moderate wind and icing conditions, and since the antenna is asymmetrical, as shown in FIG. 1*b*, that is, the planar members 1 and 2 are not identical, it is impossible to image one-half of this antenna above ground or a counterpoise.

The structures shown in FIGS. 2*a* and 2*b* are of the tapered ladder type, wherein tapered plates 5 are shunt excited by leads 6 or by a lead 6 and a counterpoise or ground plane 6'. The radiation patterns and impedance

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structures of the antenna are quite satisfactory; however, in practice its usefulness is limited to short wavelengths due to cost of the plates used and to the fact that for the longer wavelengths the solid plates 5 offer too much wind resistance and are subject to ice loading. For example, at 4 mc./s. this antenna would have solid plate radiating elements that are about 100 feet high and 35 feet wide, which not only would be highly expensive but the solid plate construction produces enormous amounts of wind drag and ice loading even at designs of much shorter wavelength.

FIG. 3*a* shows one form of the novel periodic antenna of this invention which is suitable for free space environment. Physically this antenna consists of a series of folded dipole radiators 7 each folded dipole consisting of spaced parallel dipole antennas connected together at their ends successively arranged in a plane and mutually spaced apart and in which the dimensions of the radiators and their spacing increases uniformly and proportionally with the increase in distance from the vertex of the structure. Each of the folded dipole radiators 7 consists of two rod or wire parallel dipoles, that is, two parallel wires or rods 9 and 9' which are connected together at their extremities by oppositely tapered portions. The dipole elements 7 are shunt excited from a balanced two-wire transmission line 10 by means of couplers or connections connected to wires 9' only of the folded dipoles. Each of the two wires of transmission line 10, as shown in FIGS. 3*b*, 3*c*, and 3*d*, is surrounded in the region of each of the dipole wires 9' with insulating sleeves or members 20, as of Teflon, or other low-loss dielectric material. Similar insulating members 20' surround relatively short conducting wires 12 extending parallel to the leads of line 10, which wires may have an electrical length of the order of two-tenths of an electrical wavelength though they may be lumped capacitors if desired. The insulators 20' are cut away substantially midway of their lengths to permit the dipole wires 9' to be soldered or welded to the short wires 12, as especially shown in FIG. 3*d*. In this way the wires 9' are electrically capacity coupled to the leads of transmission line 10 due to the capacity coupling between the leads of transmission line 10 and the short wires 12 and the direct connection of wires 12 to wires 9'. The insulating members 20 and 20' may be held in assembled relation upon wires 10 and 12, as by Teflon or other insulating bands 22. No connection is made between the leads of transmission line 10 and the wires 9 of the dipole 7 so that these dipole elements are shunt excited through the balanced line through use of the couplers. It will be noted that two couplers are required for each folded dipole, that is, a coupler is in proximity to each of the transmission line wires. Energy supplied, as from a source 8 when the antenna is being used as a radiator, is extracted from the transmission line to the folded dipole elements where it is radiated toward the vertex of the structure and on into the space beyond.

Electrically, energy from the antenna terminals 4—4' travels along the balanced line 10 toward the rear or large end of the structure until it reaches the active region of the antenna, the active region being the portion of the antenna in which the folded dipole elements are near resonant wavelength at the operating frequency. In practice, approximately three folded dipole elements are active at any particular frequency. In the active region the energy is coupled from the transmission line to the folded dipole elements and then radiated into space.

Since the couplers are attached to the rear or longer segment of wire 9' of each dipole radiator, energy in the shorter or forward element 9 lags in time phase from that in the longer element 9', thereby yielding a resonant phase progression in the direction toward the apex of the structure. Since the energy lags in time in the direction toward the apex or vertex of the structure, the net radiation occurs in that direction. The sharpness of the

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radiated beam, that is, the directivity, depends on the precise amplitudes and phases of the currents in the radiators and the electrical distance separating the individual radiating elements.

Preferably a matching capacitor 15 comprising a substantially U-shaped wire having insulated legs 21 extending along the two transmission lines 10 adjacent the apex of the structure is employed to prevent reflections where the parallel wires of the line join divergent portions of wires 10 of the antenna structure. This type of antenna produces a directive gain of approximately 7.5 decibels over an isotropic radiator.

In the geometry of this radiating structure as shown in FIG. 3*e*, the angle $\alpha$ defines the extremities of the folded dipole elements and their distances from the vertex of the structure may be designated as R. The subscripts $n-1$, $n$, $n+1$, etc., denote particular radiating elements, while X denotes the half lengths of these elements. The geometry is such that the pertinent dimensions, R and X, pertaining to an individual element are the geometric mean of respective adjacent element, dimensions, or

$$X_n=\sqrt{X_{n-1}X_{n+1}}$$

$$R_n=\sqrt{R_{n-1}R_{n+1}}$$

or

$$\frac{R_{n+1}}{R_n}=\frac{R_n}{R_{n-1}}=\sigma$$

$$\frac{X_{n+1}}{X_n}=\frac{X_n}{X_{n-1}}=\sigma$$

The parameter $\sigma$ in the above equations is a constant for a given antenna. This means that the folded dipole radiators differ from each other only by the scale factor, $\sigma^2$. The range of frequencies over which the structure will operate is determined by the size of the antenna, that is, by the number of radiators in the structure. Various combinations of design perameters will work satisfactorily, for example, with $\sigma=0.90$, $R_n=0.90R_{n+1}$ and $X_n=0.90X_{n+1}$. If an $\alpha$ of 40° is used, then the active portion of the antenna is approximately two-thirds of a wavelength from the apex or feedpoint of the antenna.

The radiation patterns and impedances of this novel antenna remain essentially constant over the operating frequency band. In FIG. 4 there is shown typical E and H plane patterns, the E pattern being shown in light line and the H pattern being shown in heavy line. In a typical antenna such as that shown in FIG. 3*a*, the values of the design parameters may be, for example, $\alpha=40°$, $\sigma=0.875$, and $R_1=33$ inches. Such an antenna would operate from 300 mc. to 1500 mc. Since the antenna is a balanced symmetrical structure, a central longeron 13 may be used to which each of the folded dipoles is secured to support the antenna as shown in FIG. 3*a*. This longeron is shown carried by a post 4. Also, a reflector 3 is shown at the end of the transmission line 10 and is also carried by the longeron 13.

Since the novel antenna of this invention is symmetrical it can be used as a folded monopole array, resulting in a substantial reduction in size. Such an arrangement is shown in FIGS. 5*a*, 5*b*, and 5*c*, wherein parts that are similar to FIG. 3*a* are similarly numbered, and consists of half of the folded dipole array shown in FIG. 3*a*. The antenna of FIG. 5*a* can be imaged over either the ground or a counterpoise, a counterpoise 14 being shown in FIGS. 5*a* and 5*b* and its equivalent a ground plane 23 as of sheet metal in FIG. 5*c*. It will be noted that the folded dipoles of FIG. 5*a* are carried by a catenary cable 16 suspended from a rear post support 19 through insulating U-shaped supports 17, as of Teflon or other insulating material, which are shown extending down from the cable 16 and under adjacent dipoles. Since the structure is imaged, its feed is unbalanced and is shown excited by means of a coaxial line with its outer conductor 18 being connected to the ground system and its inner conductor 19 being

coupled to wires 9' through a feed line 26 and couplers 11, as in FIG. 3a. Assuming a perfect ground system, the operation of this folded monopole array is identical to the folded dipole array of FIG. 3a. This array produces a radiation pattern that is substantially constant with frequency and as shown in FIG. 6 produces a lobe that has a miximum radiation very near the ground and is highly directive. In a typical instance a folded monopole array, such as that shown in FIG. 5a, may have the following values: $\sigma$=0.875 and $\alpha/2$ is 20°, where $\alpha$ is the vertical angle of the antenna. The distance $R_1$ in the VHF model is of the order of 40 feet and the $R_1$ in the HF model is 220 feet. An insulated matching capacitor shown consisting of a wire 25 connected to the outer conductor 18 and insulated at 25' extends along an insulated portion of the feed line conductor 19 adjacent the apex of the structure to match the concentric line to the antenna. The folded monopoles 27 of this structure are shown secured at their lower ends to a central longeron 13', which longeron is conductively connected to the counterpoise 14.

In FIG. 5c a ground or ground plane 23 as of sheet metal is used as a counterpoise.

FIG. 7 shows the VSWR's of said monopole folded antenna structure with respect to a nominal impedance of 50 ohms. The VSWR's are less than 3:1 over the operating band.

Thus it will be seen that both the novel monopole array as well as the dipole array of this invention are of extremely simple, rugged design and suitable for fabrication of large as well as small antennae, which is not true of the prior art. The dipole array being symmetrical is easily supported and can be made readily resistant to wind pressures without undue whipping whereas the monopole array is extremely simple and can be made in large sizes without undue wind pressures, which is not true of prior art antennae. Since these antennae can be fabricated from wires, fabrication costs are comparatively lower. Also, higher frequency or smaller antennae can be made rigid by fabricating the radiators from tubes which are supported by a central longeron. It is evident that wind drag and icing conditions for these antennae are much less severe than for either the non-planar log-periodic or the tapered ladder antenna.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A broadband antenna comprising a structure diverging from a vertex having a plurality of mutually spaced similar folded radiators, each such radiator consisting of a pair of spaced parallel antenna wires and conducting means electrically interconnecting the ends of said wires, the said radiators being successively arranged in a plane such that the dimensions of the radiators and their spacings increase uniformly and proportionally with increase in distance from the vertex, a feed line and capacity coupling members interconnecting one antenna wire only of each of said folded radiators to said feed line for passing alternating currents therebetween.

2. An antenna as defined in claim 1 wherein each folded radiator has its parallel antenna wires extending orthogonally with respect to the bisector of the vertex angle of said antenna, said conducting means including at least one outer connecting wire extending along a line leading to such vertex, said feed line being capacity coupled by said coupling members to the parallel wire of each radiator that is more removed from such vertex.

3. An antenna as defined in claim 2 wherein a longeron extending centrally of and along the length of said antenna is used to support said folded radiators substantially midway of the lengths of their parallel wires, said conducting means comprising connecting wires extending along lines leading to said vertex, the outer ends of the parallel antenna wires of each radiator being interconnected by said connecting wires.

4. An antenna as defined in claim 3 wherein said feed line comprises divergent leads, said capacity couplers being connected between said feed lines and the parallel wire of each folded radiator more removed from the antenna vertex.

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MULTI-BAND LOG PERIODIC ANTENNA

Filed April 3, 1964 2 Sheets-Sheet 1

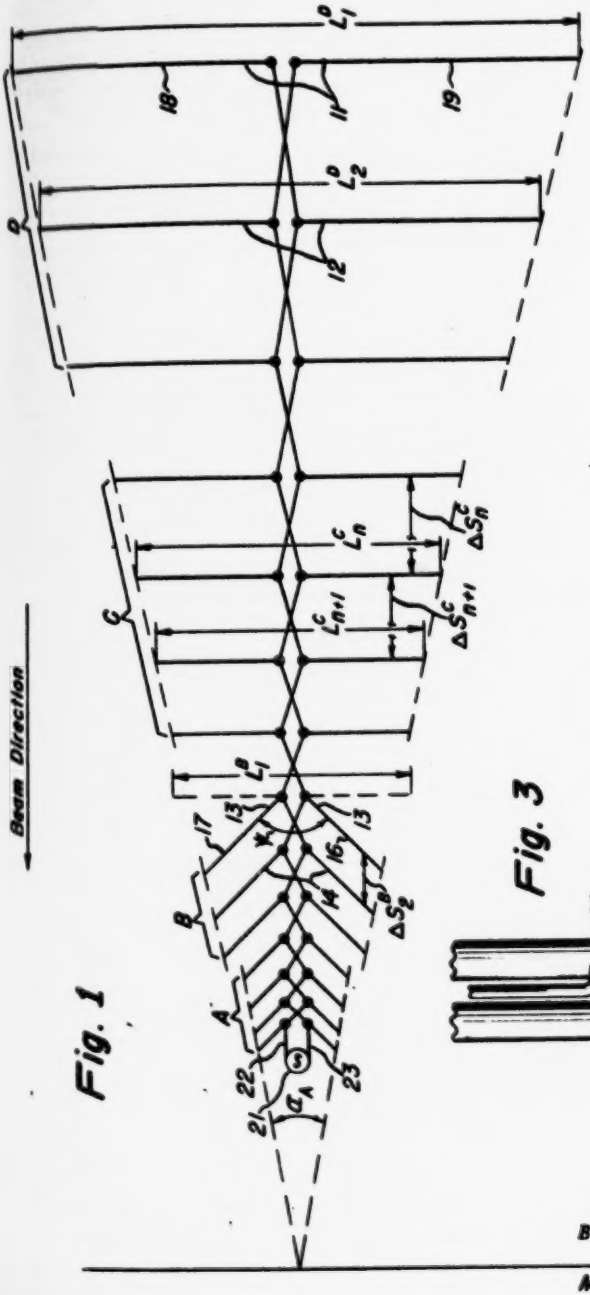


Fig. 1

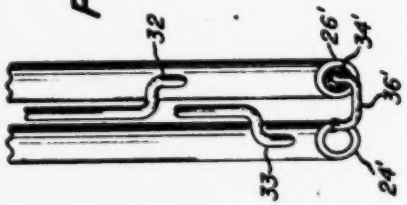


Fig. 3

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MULTI-BAND LOG PERIODIC ANTENNA

Filed April 3, 1964 2 Sheets-Sheet 2

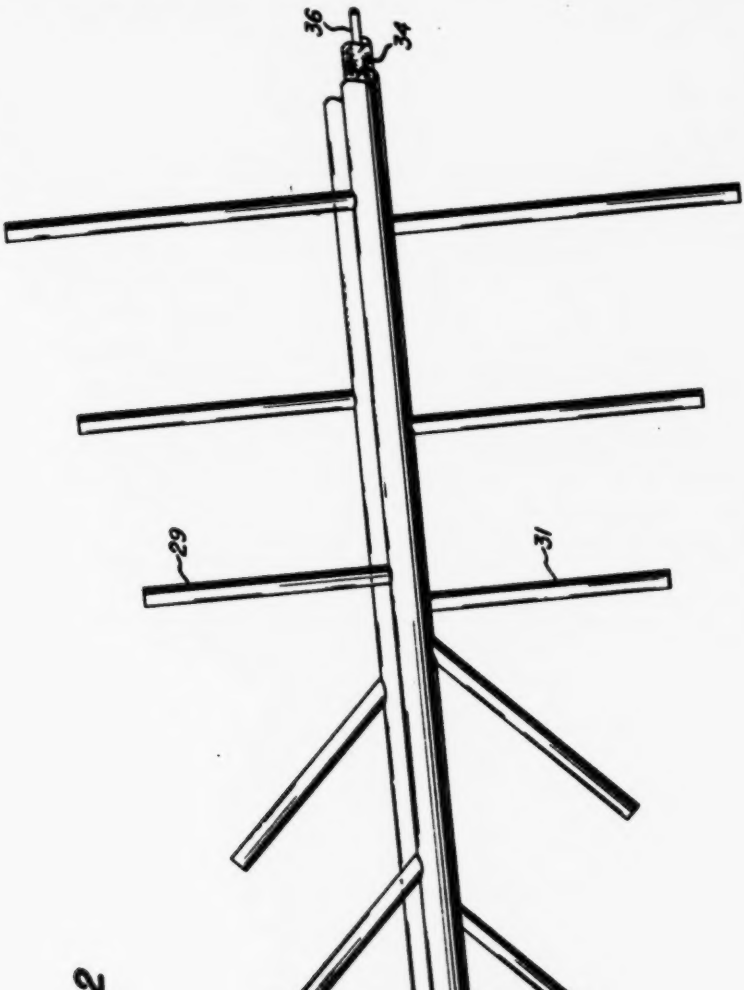


Fig. 2

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# MULTI-BAND LOG PERIODIC ANTENNA

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This invention relates to antennas. More particularly it relates to antennas having unidirectional radiation patterns that are essentially independent of frequency over wide bandwidths. Still more particularly, the antennas of the invention are designed to cover intermittent bands of frequencies which cover a wide range from the lowest frequency band to the highest.

In the copending application of Dwight E. Isbell, Serial No. 26,589, filed May 3, 1960, and in application of the inventors herein, Serial No. 59,671, filed September 30, 1960, now U.S. Patent No. 3,108,280, dated October 22, 1963, there are described certain antennas comprising coplanar arrays of dipoles or V-elements having unusually wide bandwidths performance characteristics over which bandwidths the antennas are essentially frequency independent. These antennas have input impedances which are nearly constant with unidirectional patterns and directivities comparable to yagi arrays. As described in the applications above named, the arrays comprise a number of elements which may be linear dipoles of V-elements, arranged in side-by-side relationship in a plane. The lengths of the dipoles or the developed lengths of the V-elements (i.e., the length when the sides of the V-elements are rotated to form a linear dipole) and the spacing between adjacent dipoles or V-elements are designed to vary by approximately chosen scale factors according to a definite mathematical formula, with each of the elements being fed at its midpoint by a common feeder which has appropriate phasing between successive elements. The elements which are used to make up the arrays vary progressively in length in accordance with the scale factor selected.

In the linear dipole version, described in the aforementioned Isbell application, the length of the longest dipole element corresponds to about ½ wavelength at the low frequency limit of the antenna's effective range, while the shortest element has a length corresponding to about ⅜ of a wavelength at the upper frequency limit. On the other hand, the antennas described in the present inventors' copending application, Serial No. 59,671, in which the elements are V-shaped, have increased directivity at frequencies above the ½ wavelength mode of operation and therefore have effective frequency ranges which are greater than those of a comparable linear dipole antenna.

The antennas of the instant invention are related to those described above, but differ therefrom in that the former are designed so that their effective frequency range is not continuous from the high limit to the low limit but is rather broken up into a number of discrete bands within which bands the antenna performs satisfactorily. There are a number of instances in which antennas of this type will be found particularly useful. For example, the frequencies assigned to VHF and UHF television transmission are divided into a number of discrete frequency bands. Thus, television channels 2, 3, and 4 of the lower VHF range cover frequencies from 54 to 72 mcs., the mid-VHF band containing television channels 5 and 6 extends from 76 to 88 mcs. and the upper VHF band, including television channels 7–13, extends from 174 to 216 mcs., while television channels 14–83 of the UHF band extend from 470 to 890 mcs.

An antenna made in accordance with the present invention can effectively cover all of the above frequency bands, but not the intervening ranges between the bands of interest, and this antenna is considerably smaller in overall size and weight and, therefore, less expensive than an antenna designed to cover continuously the entire range of television frequencies from 54 to 890 mcs. Furthermore, the directive gain increases in the higher modes which are used to cover the higher frequency bands, thus making more effective use of the size of the structure.

Another application of the invention occurs in antennas designed for use by amateur radio operators whose transmissions are restricted by law to certain frequency bands. The "ham" radio operator is, therefore, interested in an antenna which performs effectively in those ranges in which he is free to operate and which need not be effective in the intervening frequency bands. Such an antenna can also be made in accordance with the invention in a smaller version than has been heretofore possible, without sacrificing bandwidth or directivity.

The invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a schematic plan view of an antenna made in accordance with the principles of the invention;

FIGURE 2 is a perspective view of a practical antenna embodying the invention; and

FIGURE 3 is a fragmentary view of an improved and preferred form of an antenna similar to that shown in FIGURE 2, as seen from a point directly in front of and above the narrow end of the antenna.

Referring to FIGURE 1, it will be seen that the antennas of the invention are composed of a plurality of elements, which may either linear dipoles, e.g., 11 and 12, or V-shaped elements, e.g., 13 and 14, or a combination of both as shown, arranged in side-by-side relationship. The elements are arranged in a number of zones, or groups, e.g., A, B, C, and D. The distinguishing characteristic of the zones found in the antenna is the fact that the ends of the elements within a zone fall on a pair of converging straight lines, as shown in the drawing. It is also characteristic of the antennas of the invention that the converging lines defining the ends of the elements in a given zone are not collinear with the corresponding converging lines associated with another zone of the antenna having the same type (i.e., linear dipole or V-element) of element. Thus, for example, since zones C and D are both comprised of linear dipoles, the converging lines defining their terminals are not collinear. This is also true of zones A and B which are also composed of similar elements. When adjacent zones are composed of dissimilar elements, however, as in the case of zones B and C, wherein B has V-elements and C has linear elements, the converging lines passing through the terminals of the elements of the zone may or may not be collinear. Furthermore, the angle formed by these converging lines, e.g., $\alpha_A$ in FIGURE 1, may or may not be equal for each zone, although all such angles preferably have values between about 20° and about 100°. In the antenna shown in FIGURE 1, $\alpha_A$ is represented as the angle defined by the converging lines passing through the outer ends of the elements in zone A. This angle might or might not be equal to that angle which would be formed on extending the lines passing through the ends of the elements of zone B to a meeting point. Similar considerations could be had relative to the angle which would result were a line to be drawn past the ends of all elements of zones C and D.

It will be seen from FIGURE 1 that zones A and B are composed of a plurality of V-elements, each of which consists of a pair of arms, e.g., 16 and 17, defining an apex in the middle of the V-element, said V-elements

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being arranged in a herringbonelike pattern. The arms of a given V-element are equal in length and the related arms of the several V-elements within a zone, i.e., the arms on the same side of a line passing through the apexes of the V-elements, are preferably substantially parallel to each other.

In a similar manner the linear dipoles which constitute zones C and D of the antenna of FIGURE 1 are each composed of a pair of arms, e.g., **18** and **19**, which are equal in length and which are preferably substantially parallel to the corresponding arms of the other dipoles within the zone. With respect to all zones, i.e., both those consisting of V-elements and those formed of linear dipoles, it is preferred that the antenna be symmetrical about a line passing through the midpoints of the linear dipoles and the apexes of the V-elements, respectively, as shown.

The antenna is fed at its narrow end from a conventional source of energy, depicted in FIGURE 1 by way of illustration only as alternator **21**, by means of a balanced feeder line consisting of conductors **22** and **23**. It will be seen that the crossed feeder lines **22** and **23** are twisted between connections to consecutive or adjacent elements of the antenna.

The length of an element (dipole or V-element) in the antenna shown in FIGURE 1 is designated herein as $L_n^X$, where $n$ is used to designate any element in the zone which is designated as X. Thus, for example, the longest element in the antenna of FIGURE 1, which is the longest dipole of group D, is designated as $L_1^D$, meaning element No. 1 of zone D. Thus, in general, the subscript ($n$) indicates the order of the particular element in the group designated by the superscript (X). It will be further seen that in the case of V-elements, such as those of zone B, the effective length of a V-element is taken to be the length which the arms of the V-element have when developed so that these arms are collinear. As shown, the length $L_1^B$ is the developed length of V-element **13**.

The lengths of the elements in the antennas of the invention, and the spacing between these elements are related by a scale factor $\tau$ which is constant within a given zone and is defined by the following equations:

$$\tau^X = \frac{L_{(n+1)}{}^X}{L_n{}^X} = \frac{\Delta S_{(n+1)}{}^X}{\Delta S_n{}^X}$$

where $\tau^X$ is a constant having a value less than 1, $L_n^X$ is the length of a dipole (or the developed length of a V-element) in zone X of the antenna, $L_{(n+1)}^X$ is the corresponding length of the adjacent smaller element in group X, $\Delta S_n^X$ is the spacing between the element having the length $L_n$ and the adjacent larger element in group X, and $\Delta S_{(n+1)}^X$ is the spacing between the element having the length $L_n$ and the adjacent smaller element in group X.

In the foregoing, it will be observed that the same scale factor, $\tau$, may be used to determine both dipole length and spacing. This will, under normal conditions, represent optimum operational conditions. However, if efficiency of a lesser degree can be tolerated, it is, at times, possible to operate with a different scale factor for determining the dipole length from that which determines spacing. At such times, a scale factor $\tau_1$ may be used to determine the dipole length and a scale factor $\tau_2$ may be used to control spacing the dipole sections.

Each dipole and the feeder connecting thereto in the region between one dipole pair and the next adjacent dipole pair may be regarded as a "cell." The lengths of dipoles and the spacings then are so selected by the determined scale factors that the combination of dipole lengths and spacings, when combined as here described, provide the desired substantially uniform wideband responses in the desired frequency ranges.

As noted above, the elements comprising the antennas of the invention may be either linear dipoles or V-

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elements. With respect to the latter, the arms of the individual V-elements are inclined to point in the direction of decreasing element size so that the apex of each of the V-elements points in a direction away from the angle formed by the lines passing through the extremities of the individual elements. The angle, $\psi$, formed at the apexes of the V-elements by the arms thereof, preferably has a value between about 50° and 150°.

It will be noted that in FIGURE 1 the angle $\alpha_A$ is that formed by the lines passing through the extremities of the elements in zone A. In a similar manner, although not shown in the drawing, the lines passing through the extremities of the elements in zones B, C, D, etc., could be extended to form similar angles $\alpha_B$, $\alpha_C$, $\alpha_D$, respectively. Each of these angles $\alpha_B$, $\alpha_C$, $\alpha_D$, etc., may be equal to each other, and in the preferred embodiment of the antenna are equal, but this is not a necessary condition. In any event, it is preferred that these angles, whether or not they are equal to each other, have values within the range from about 20° to 100°.

The advantages of the antennas of the invention stem from the discovery that when a given antenna is in operation at a certain frequency there are involved only a few of the elements of which the antenna is formed. It has been found possible, therefore, to remove from the antenna structure those elements which are not involved at this frequency and bring the adjacent parts of the antenna together to close the gap which would exist, and it has been further found that this modification of the antenna is possible without affecting the performance on either side of the excluded region. Taking the antenna of FIGURE 1 as an example, the element which would have formed the fourth element of Zone D is not required when the antenna is operated at a frequency which is dependent on the lengths of elements 1, 2 and 3. Accordingly, and since the antenna is not intended to operate at a frequency represented by this hypothetical fourth element, the element can be omitted from the antenna with a consequent saving in size, weight, and cost, without, however, adversely affecting the operation of the remaining elements in the antenna at their characteristic frequencies. In a similar manner the elements which would normally have appeared in the antenna between zones A and B have been omitted with no adverse effects on the operation of the antenna at the frequencies corresponding to the elements found in zones A and B.

The antennas of the invention contain a plurality of zones or groups as defined above, all of which may contain linear dipoles and some V-elements as desired. The use of V-elements in the antennas of the invention rather than dipoles increases the directivity of the antennas and also permits more effective utilization of a given antenna, since the same structure can be used in several frequency modes to achieve coverage of different frequency bands. In the case of an antenna zone or group consisting entirely of straight dipoles, the effective frequency range of such a zone is that in which the low limit corresponds to the frequency at which the largest element in the zone is about ½ wavelength long, and the upper frequency limit to the frequency at which the smallest dipole in the group is about ⅜ wavelength long. In general, therefore, it may be said that the frequency range of a straight dipole group of elements corresponds to the mode of operation in which the lengths of the dipoles in the group are about ½ wavelength long. As the frequency is raised above the upper limit of the ½ wavelength mode in the group, the elements will also be found to radiate or receive effectively at frequencies in which the dipoles are about ⅔ wavelengths long (the ⅔ wavelengths mode), ⅝ wavelengths long (the ⅝ wavelengths mode), and so on. At frequencies above the ½ wavelength mode, however, the pattern of a straight dipole group becomes multilobed and is therefore of limited usefulness. By inclining the arms of the dipoles to form V-elements, it has been found

that a single lobe of improved directivity may be obtained as the frequency is raised from the ½ wavelength mode through the intervening ranges to the ⅝ wavelengths mode and beyond. For each mode of operation there exists an optimum value for the angle $\psi$, ranging from about 114° for the ½ wavelength mode to about 62° for the ⅝ wavelengths mode. By using a compromise value for $\psi$ within this range, however, a zone of V-elements can be made to achieve acceptable performance over several modes of operation, thereby increasing its effective range. This result is possible since many of the elements forming the antenna array are used at more than one frequency.

The construction of a practical antenna made in accordance with the invention is shown in FIGURE 2. In this antenna the balanced line consists of two closely spaced and parallel electrically conducting small diameter tubes **24** and **26**, to which are attached the arms which form the V-elements and the straight dipoles. It will be noted that each of the arms making up one straight dipole, e.g., **29** and **31**, or one V-element, e.g., **27** and **28**, is connected to a different one of said conductors **24** and **26**. Moreover, considering either one of conductors **24** and **26**, consecutive arms along the length thereof extend in opposite directions. It will be seen that this construction has the effect of alternating the phase of the connections between successive elements, as depicted schematically in FIGURE 1. Although the elements of the antenna of FIGURE 2 are not precisely coplanar, differing therefrom by the distance between the parallel conductors **24** and **26**, in practice this distance is usually small so that the arms of the elements are substantially coplanar and the advantages of the invention are maintained. In some instances, however, it may be advantageous to bend the individual arms, e.g., **32** and **33** in FIGURE 3, close to the point of attachment to the feeder lines **24'** and **26'**, so as to position all the arms in the same plane. The antennas of FIGURES 2 and 3 may be conveniently fed by means of a coaxial cable, e.g., **34** and **34'** positioned within conductor **26** or **26'**, the outer conductor of the cable making electrical contact with the conductor **26** or **26'** and the central conductor **36** or **36'** of the cable extending to and making electrical connection with conductor **24** or **24'** as shown.

In addition to the type of construction shown in FIGURES 2 and 3, practical antennas made in accordance with the invention can use a balanced feeder line which is twisted between connections to successive dipoles or V-elements. Other suitable means for accomplishing the desired phasing, such as transmission line loops or stubs, can also be used.

As an example of the invention, an antenna was constructed in a manner similar to that shown in FIGURE 3 containing two zones of elements, a group of V-elements, such as group A in FIGURE 1, and a group of linear dipoles, such as group C. The antenna was made using 0.125" diameter tubing for the balanced line and 0.050" diameter wire for the arms of the elements. The arms were soldered to the feeder line and the array was fed by a miniature coaxial cable inserted into one of the conductors of the balanced line. The antenna had a total of 12 elements, of which 6 were contained in a zone of linear dipoles partially defined by $\tau=0.90$. The linear dipoles ranged in length from about 7.5 inches to about 4.4 inches, the zone having a length of about 2 inches. The antenna also contained a group of six V-elements ($\psi=70°$) ranging in developed length from about 3.3 inches to about 2.6 inches, the group of elements having a length of about 1.1 inches, and being further defined by $\tau=0.95$. This antenna was a scale model of one designed to cover the 15 meter, 10 meter, 6 meter and 2 meter bands of amateur radio transmission. For the 15 and 10 meter bands the antenna was operated in the ½ wavelength mode as a linear dipole array. The 6 meter band was covered by the V-elements of the antenna in the ½ wavelength mode and the 2 meter band was covered by the same V-elements in the ⅝ wavelength mode. This antenna was found to perform acceptably over this range, although the performance in the 6 meter band was somewhat inferior to the other bands which were covered. This deficiency, however, could have been rectified by providing an additional large element in the group of V-elements.

It is believed evident from the above description that the antennas of the invention can be designed to cover discrete frequency bands within a wide overall range as desired. By using the principles of the invention, the antenna can be made smaller in length and consequently cheaper to construct that has heretofore been possible, without, however, sacrificing performance within the desired frequency bands.

This application constitutes a continuation-in-part of U.S. patent application Serial No. 76,075, filed by the inventors herein named on December 15, 1960, now abandoned, and a continuation-in-part of U.S. patent application Serial No. 299,715, also filed by the inventors herein named and carries a filing date of August 5, 1963, now abandoned.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A broadband unidirectional antenna covering an intermittent range of frequencies comprising an array of a plurality of substantially coplanar elements, said elements being arranged in a plurality of zones, the ends of the elements in each of said zones falling on a pair of converging lines, the lines passing through the ends of the elements in any zone being non-collinear with at least one pair of the corresponding lines associated with any other zone, the elements within any zone being arranged in substantially parallel side-by-side relationship and progressively increasing in length and spacing, the ratio of the lengths of any two adjacent elements within any one of said zones being given by the formula

$$\frac{L_{n+1}}{L_n}=\tau$$

where $L_n$ is the length of the larger of said adjacent elements, $L_{n+1}$ is the length of the adjacent smaller element, and $\tau$ is a constant having a value less than 1, the spacing between the elements of any zone being given by the formula

$$\frac{\Delta S_{n+1}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the element having the length $L_n$ and the adjacent larger element, $\Delta S_{n+1}$ is the spacing between the element having the length $L_n$ and the adjacent smaller element, and $\tau$ has the significance previously assigned, said elements being fed by a common feeder which alternates in phase between successive elements.

2. The antenna of claim 1 in which the elements in at least one of said zones are parallel dipoles.

3. The antenna of claim 1 in which the elements in at least one of said zones are V-elements arranged in a herringbonelike arrangement, each of said elements having a pair of equal arms defining an apex, the apexes of said V-elements lying on a straight line, the corresponding arms of said elements being parallel.

4. The antenna of claim 3 wherein the angle formed by the arms of any V-element at the apex thereof has a value within the range from about 50° to about 150°.

5. The antenna of claim 1 wherein the angles formed by the lines passing through the ends of the elements in said zones have values within the range from about 20° to about 100°, and the values of the constant $\tau$ associated

with said zones lie within the range from about 0.8 to about 0.95.

6. A broadband unidirectional antenna covering an intermittent range of frequencies comprising an array of a plurality of substantially coplanar conducting elements, said elements being arranged in a plurality of zones, the ends of the elements in each of said zones falling substantially on a pair of converging lines, the lines passing substantially through the ends of the elements in any zone being non-collinear with at least one pair of the corresponding lines associated with any other zone, the elements within any zone being arranged in substantially parallel side-by-side relationship and progressively increasing in length, the ratio of the lengths of any two adjacent elements within any one of said zones being determined by a zonal scale factor established by the ratio of the length of one conducting element to the length of the next adjacent and longer conducting element to establish the length scale factor, the spacings of one conducting element to the next smaller element and the spacing of the same conducting element to the next longer conducting element with each zone establishing the spacing scale factor, and where each scale factor in each zone is a constant, and a common two-conductor feeder connected to all of the elements with adjacent conductor elements being connected to different conductors of the feeder.

7. The antenna of claim 6 in which the elements in at least one of said zones are parallel dipoles extending in a direction substantially perpendicular to the axis of the feeder.

8. The antenna of claim 6 in which the elements in at least one of said zones comprises V-elements arranged in a herringbonelike arrangement, each of said elements having a pair of equal arms defining an apex, the apexes of said V-elements lying on a straight line, the corresponding arms of said elements being parallel, and in which at least one other zone comprises dipole elements extending substantially normal to the feeder axis.

9. An aerial system for wide-band use over selected intermittent frequency ranges comprising a plurality of substantially coplanar elements arranged in a plurality of zones, at least one zone comprising a plurality of herringbonelike conducting V-elements arranged to terminate in planar relationship, at least one other zone comprising a plurality of parallel dipoles, a two-conductor balanced feeder connected to the elements forming each zone at substantially the inner end thereof, each two opposite V-elements and each two opposite parallel dipoles forming a pair constituting dipole halves, the connection from each adjacent conducting element of the dipole sections being to a different feeder, all of said elements being selectively spaced from each other, each element of each pair of conducting V-elements having arms of substantially equal length substantially defining an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and terminating at the feeder, each of the parallel dipoles all lying in a common plane and also terminating at the feeder, the said V-elements and parallel dipoles of each pair being of different electrical lengths with successive V-elements and dipoles differing in electrical length with respect to each other by substantially the same scale factor, each V-element and each dipole and the feeder between successive V-elements and dipoles constituting a cell, and the selective spacings between adjacent dipoles decreasing from one end to the other with the greater spacing being between the longest dipoles and being such that the combination of V-elements and dipole lengths and spacings provides a substantially uniform wide-band response over a plurality of selected frequency bands, the connection between the V-elements and the dipoles and the feeder being made in such a manner that the directive gain of the antenna increases as operation shifts from one band to an adjacent band of higher frequencies, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements and dipole elements and in the direction of the smallest of the elements.

10. An aerial system for wide-band use covering intermittent frequency ranges comprising an array of a plurality of substantially coplanar conducting elements arranged in a plurality of zones, the conducting elements of each zone being similar, at least one zone comprising a plurality of herringbonelike conducting V-elements planarly arranged, at least one other zone comprising a plurality of substantially straight and oppositely positioned conductor elements, a two-conductor balanced feeder connected to each of said conducting elements at substantially the inner end thereof, each two opposite V-elements forming a pair constituting dipole halves each two oppositely positioned elements also forming a pair constituting dipole halves, the connection from each adjacent dipole section being to a different feeder, said V-elements of the zone being selectively spaced from each other, the elements of each pair of V-elements and each pair of oppositely positioned elements having arms of substantially equal length, the V-elements of one zone substantially defining an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and terminating at the feeder and the oppositely positioned elements of a second zone also terminating at the feeder, the said dipoles of each pair being of different electrical lengths with successive dipoles in each zone differing in electrical length with respect to each other by substantially the same scale factor, each dipole and the feeder between successive dipoles constituting a cell, and the selective spacings between adjacent dipoles decreasing from one end to the other with the greater spacing being between the longest dipoles and being such that the combination of dipole lengths and spacings provides a substantially uniform wide-band response over a plurality of frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the dipoles and the feeder being made in such a manner that the directive gain of the antenna increases as operation shifts from one band to an adjacent band of higher frequencies, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements and in the direction of the smallest of the V-elements.

11. An aerial system for wide-band use covering intermittent frequency ranges comprising a plurality of pairs of substantially coplanar conducting elements, the elements being arranged in a plurality of zones, a two-conductor balanced feeder connected to each of said elements at substantially the inner end thereof, the elements within each zone being arranged in substantially parallel side-by-side relationship and progressively differing length and spacing, the connection from each adjacent element being to a different feeder, each pair of elements having arms of substantially equal length, the ratio of the lengths, of any two adjacent elements within any one of said zones being determined and substantially proportioned by a length scale factor established by the ratio of the length of one of the conducting elements to the length of the next adjacent longer conducting element so that the elements of each pair have different electrical lengths and successive elements with each zone differ in electrical length with respect to each adjacent element by substantially the same scale factor, each conductor and the feeder between successive conductors constituting a cell, the ratio of the spacing of one conducting element in each zone to the next smaller element and the spacing of the same conducting element in the said zone to the next longer conducting element also establishing a spacing scale factor, each of the scale factors having a value of less than unity so that the selective spacings between adjacent conductors differ from one end to the other with the greater spacing being between the longest conductors

and being such that the combination of conductor lengths and spacings provides a substantially uniform wide-band response over the zone, the connection between the conductors and the feeder being made in such a manner that the directive gain of the antenna increases as operation shifts from one band to an adjacent band of higher frequencies, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the conducting elements and in the direction of the smallest of the said elements.

12. The antenna claimed in claim 11 in which the conducting elements of the zones are arranged in V-formation with the open end of the V faced toward the feeder connection.

13. The antenna claimed in claim 11 in which the conducting elements of the separate zones are parallel dipoles.

14. The antenna claimed in claim 11 in which the conducting elements of each zone are of similar form and the conducting elements of at least one zone are arranged in V-formation with the open end of the V faced toward the feeder connection and in which the conducting elements of at least one other zone are parallel dipoles.

15. A broad band unidirectional antenna covering intermediate ranges of a wide frequency spectrum comprising a multiplicity of substantially coplanar conductor elements, each conductor element forming half of a dipole, the two elements of each dipole being of substantially the same length, the several dipole elements being selectively spaced along an axis and arranged in a plurality of separate zones, the electrical length of the dipoles decreasing with distance along the axis, the electrical length of adjacent dipole elements of the separate zones differing by a selected zone scale factor which is substantially constant in each zone, the electrical length of each dipole of all zones being approximately an odd multiple of a half-wave length at a frequency within the operating spectrum over which the antenna is to provide maximum response in each zone, a pair of feeder conductors for feeding all of the dipole elements, one element of each dipole being connected to one feeder conductor and the other element of each dipole being connected to the opposite feeder conductor, adjacent elements of different dipoles being connected to opposite feeder conductors so that the directional gain of the antenna is maximum in the direction along the feeder from the end with longer dipoles toward the end with shorter dipoles and increases as the operation shifts from one frequency within the spectrum whereat the element lengths are approximately an odd integral number of half-wave lengths to the next higher frequency range where the element lengths are once more approximately an odd integral number of half-wave lengths, the ratio of the lengths of any two adjacent dipole elements within any one of the zones being determined by the zonal scale factor of substantially constant value within the zone, and means to connect the feeder conductors to an external circuit at a location which is substantially removed from the longest dipole element in the direction of the shortest dipole element.



16. The antenna claimed in claim 15 wherein the dipole elements of at least one of the zones extend in a direction substantially perpendicular to the axis of the feeder conductors.

17. The antenna claimed in claim 15 in which the dipole elements of at least one of the zones comprise V-shaped elements whose apexes lie on substantially a straight line and between which elements in the region of the open portion of the V-formation there is an angular spacing in the range from about 50° and 150°.

18. The antenna claimed in claim 15 wherein the corresponding dipole elements of each zone extend parallel to each other and wherein certain of the dipoles extend substantially perpendicular to the feeder and wherein other dipoles are V-shaped elements whose apexes lie on substantially a straight line with the angular spacing between the elements of the open portion of the V-formation being within the angular limits of 50° and 150°.

No references cited.

# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,150,376 September 22, 1964

Robert L. Carrel et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 33, after "may" insert -- be --; column 3, lines 44 to 46, the equation should appear as shown below instead of as in the patent:

$$\tau X = \frac{L^X_{(n+1)}}{L^X_n} = \frac{\Delta S^X_{(n+1)}}{\Delta S^X_n}$$

line 47, for "$L_n{}^X$" read -- $L^X_n$ --; line 49, for "$L_{(n+1)}{}^X$" read -- $L^X_{(n+1)}$ --; line 51, for "$\Delta S_n{}^X$" read -- $\Delta S^X_n$ --; line 53, for "$\Delta S_{(n+1)}{}^X$" read -- $\Delta S^X_{(n+1)}$ --; column 6, line 7, for "large" read -- larger --; line 14, for "that" read -- than --; column 8, line 58, strike out the comma.

Signed and sealed this 5th day of January 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

JFD EXHIBIT 2E.

Oct. 5, 1965 D. E. ISBELL 3,210,767

FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNAS

Filed May 3, 1960 2 Sheets-Sheet 1

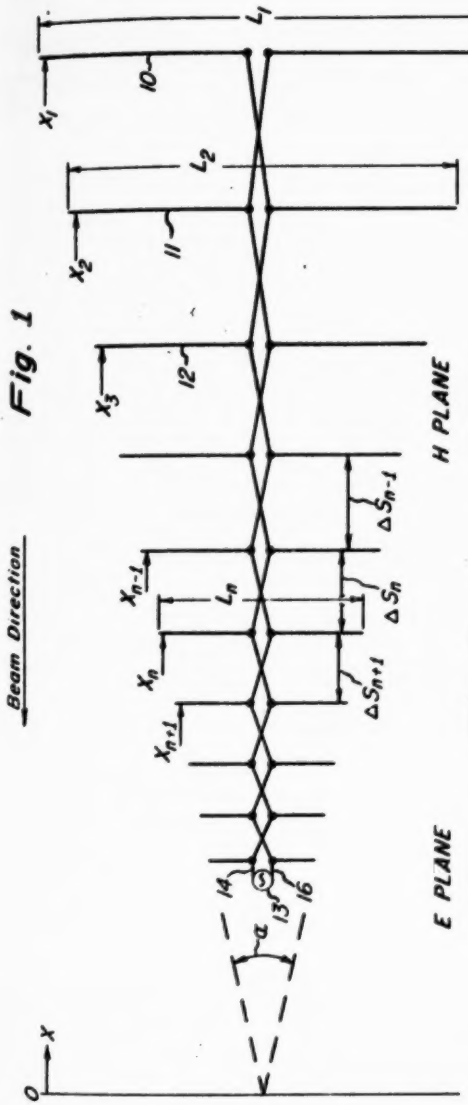


Fig. 1

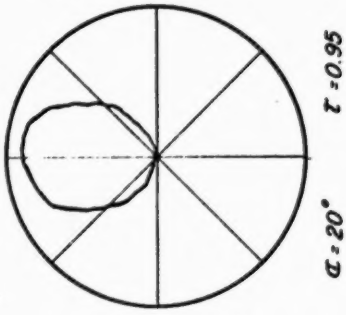


Fig. 4

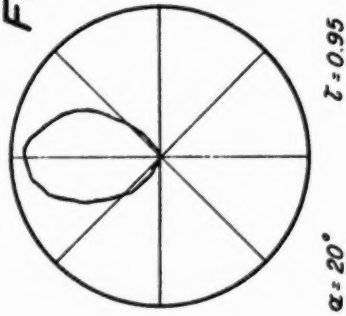


Fig. 3

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FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNAS

Filed May 3, 1960 2 Sheets-Sheet 2

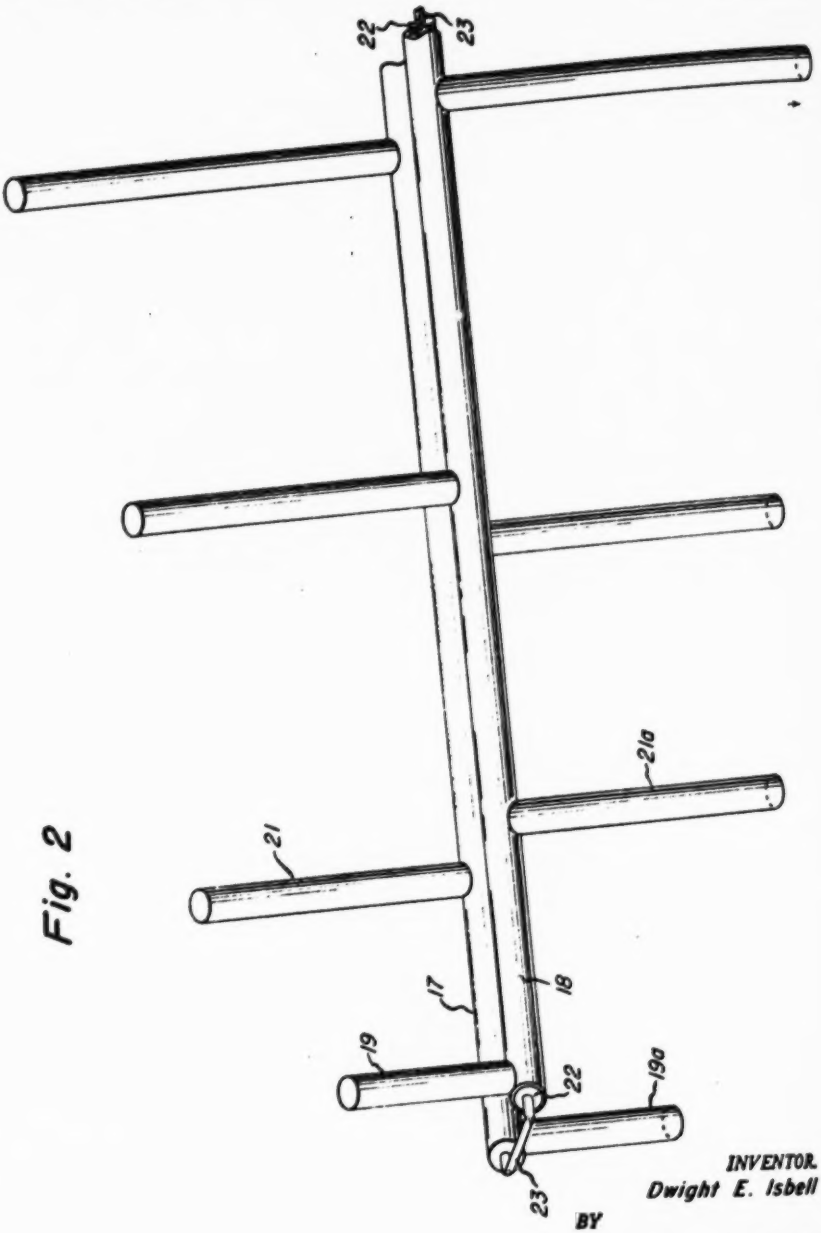


Fig. 2

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United States Patent Office

3,210,767

Patented Oct. 5, 1965



# 3,210,767
# FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNAS

Dwight E. Isbell, Seattle, Wash., assignor to The University of Illinois Foundation, a non-profit corporation of Illinois

Filed May 3, 1960, Ser. No. 26,589
15 Claims. (Cl. 343—792.5)

This invention relates to antennas, and more particularly, it relates to antennas having unidirectional radiation patterns that are essentially independent of frequency over wide bandwidths.

The antennas of the invention are coplanar dipole arrays consisting of a number of dipoles arranged in side-by-side relationship in a plane, the length and the spacing between successive dipoles varying according to a definite mathematical formula, each of the dipoles being fed by a common feeder which introduces a phase reversal of 180° between connections to successive dipoles. The antennas of the invention provide unidirectional radiation patterns of constant beamwidth and nearly constant input impedances over any desired bandwidth.

The invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying drawing, in which:

FIGURE 1 is a schematic plan view of an antenna made in accordance with the principles of the invention;

FIGURE 2 is an isometric view of a practical antenna embodying the invention; and

FIGURES 3 and 4 are radiation patterns of a typical antenna, in the E plane and H plane, respectively.

Referring to FIGURE 1, it will be seen that the antenna of the invention was composed of a plurality of dipoles 10, 11, 12, etc., which are coplanar and in parallel, side-by-side relationship. It will be noted that the lengths of the successive dipoles and the spacing between these dipoles is such that the ends of the dipoles fall on a pair of straight lines which intersect and form an angle $\alpha$. In the preferred embodiment the antenna is symmetrical about a line passing through the midpoints of the dipoles, as shown.

The antenna is fed at its narrow end from a conventional source of energy, depicted in FIGURE 1 by alternator 13, by means of a balanced feeder line consisting of conductors 14 and 16. It will be seen that the feeder lines 14 and 16 are alternated between connections to consecutive dipoles, thereby producing a phase reversal between such connections.

The lengths of the dipoles and the spacing between dipoles are related by a constant scale factor $\tau$ defined by the following equations:

$$\tau = \frac{L_{(n+1)}}{L_n} = \frac{\Delta S_{(n+1)}}{\Delta S_n}$$

where $\tau$ is a constant having a value less than 1, $L_n$ is the length of any intermediate dipole in the array, $L_{(n+1)}$ is the length of the adjacent smaller dipole, $\Delta S_n$ is the spacing between the dipole having the length $L_n$ and the adjacent larger dipole, and $\Delta S_{(n+1)}$ is the spacing between the dipole having the length $L_n$ and the adjacent smaller dipole.

It will be seen from the geometry of the antennas, as given above, that the distance from the base line 0 at the vertex of the angle $\alpha$ to the dipoles forming the array are defined by the equation:

$$\tau = \frac{X_{(n+1)}}{X_n}$$

where $X_n$ is the distance from the base line 0 to the dipole having the length $L_n$, $X_{(n+1)}$ is the corresponding distance



from the base line to the adjacent smaller dipole, and $\tau$ has the significance previously given.

The radiation pattern of the antennas of the invention, having the geometrical relationship among the several parts as defined above, is unidirectional in the negative X direction, i.e., extending to the left from the narrow end of the antenna of FIGURE 1.

The construction of an actual antenna made in accordance with the invention is shown in FIGURE 2. In this antenna the balanced line consists of two closely-spaced and parallel electrically conducting small diameter tubes 17 and 18 to which are attached the dipoles, each of which consists of two individual dipole elements, e.g., 19 and 19*a*, 21 and 21*a*, etc. It will be noted that each of the two elements making up one dipole is connected to a different one of said conductors 17 and 18, in a direction perpendicular to the plane determined by said conductors 17 and 18. Moreover, considering either one of the conductors 17 and 18, consecutive dipole elements along the length thereof extend in opposite directions. It will be seen that this construction has the effect of alternating the phase of the connection between successive dipoles, as depicted schematically in FIGURE 1. Although the dipoles of FIGURE 2 are not precisely coplanar, differing therefrom by the distance between the parallel conductors, in practice this distance is very small so that the dipole elements are substantially coplanar and the advantages of the invention are maintained. The antenna of FIGURE 2 may be conveniently fed by means of a coaxial cable 22 positioned within conductor 18, the central conductor 23 thereof extending to and making electrical connection with conductor 17 as shown.

As an example of the invention, an antenna of the type shown in FIGURE 2 was constructed using 0.125 inch diameter tubing for the balanced line and 0.050 inch diameter wire for the elements. The elements were attached to the feeder line with soft solder, and the array was fed with miniature coaxial cable inserted through one of the balanced line conductors. The antenna was defined by the parameters $\tau = 0.95$ and $\alpha = 20°$. The antenna had a total of 15 dipoles, with the longest dipole element being 2½" long, while the shortest element was one-half of this length, or 1¼". The array was 7½" long.

Typical radiation patterns for the above-described antenna in the E plane and the H plane are shown in FIGURES 3 and 4, respectively. These patterns were found to remain essentially constant over the band of about 1100 to 1800 mc./sec. The minimum front-to-back ratio over this band was 17 db and the directivity over the range from about 1130 to 1750 mc./sec. was better than 9 db over isotropic.

The performance of the above-described antenna clearly indicates that the antennas of the invention provide excellent rotatable beams for use particularly in the HF to UHF spectrum. In comparison to the well-known parasitic types of antennas which bear some resemblance to those of the invention, such as the Yagi array, the antennas of the invention provide a much wider bandwidth with essentially comparable directivity. Advantageously, however, the antennas of the invention need no adjusting for their performance over a wide bandwidth, compared to the parasitic types which must be adjusted by cut-and-try procedures for each frequency. Further experimental work with other antennas similar to that described above has indicated that the preferred values for the parameters which define the antennas of the invention include a range of values for angle $\alpha$ between about 20° and 100°, with $\tau$ having a value between about 0.8 and about 0.95. When these parameters have values within the preferred ranges the antennas were

found to have essentially frequency independent performance over any desired bandwidth. The upper and lower limits of the bandwidths may be adjusted as desired by fixing the lengths of the longest dipole and the shortest dipole, respectively. It has been determined experimentally that the longest dipole element should be approximately 0.47 wavelength long at the lower limit and the shortest element should be about 0.38 wavelength long at the upper limit. Moreover, in order to provide a suitable front-to-back ratio at the low frequency limit, there should be at least 3 dipoles in the array and preferably about 10 to 30 dipoles.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A broadband unidirectional antenna comprising an array of substantially coplanar and parallel dipoles of progressively increasing length and spacing in side-by-side relationship, the ratio of the lengths of any two adjacent dipoles being given by the formula

$$\frac{L_{(n+1)}}{L_n}=\tau$$

where $L_n$ is the length of any intermediate dipole in the array, $L_{(n+1)}$ is the length of the adjacent smaller dipole and $\tau$ is a constant having a value less than 1, the spacing between said dipoles being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the dipole having the length $L_n$ and the adjacent larger dipole, $\Delta S_{(n+1)}$ is the spacing between the dipole having the length $L_n$ and the adjacent smaller dipole, and $\tau$ has the significance previously assigned, said dipoles being fed in series by a common feeder which alternates in phase between successive dipoles.

2. The array of claim 1 which is symmetrical about a line passing through the midpoint of each dipole in the array.

3. A broadband unidirectional antenna comprising an array of a plurality of substantially coplanar and parallel dipoles of progressively increasing length in side-by-side relationship, the ends of said dipoles falling on a V-shaped line forming an angle $\alpha$ at its vertex, the ratio of the lengths of any pair of adjacent dipoles being given by the formula

$$\frac{L_{(n+1)}}{L_n}=\tau$$

where $L_n$ is the length of the longer dipole of the pair, $L_{(n+1)}$ is the length of the shorter dipole, and $\tau$ is a constant having a value less than 1, the dipoles in said array being fed in series by a common feeder which alternates 180° in phase between successive dipoles.

4. The antenna of claim 3 in which the angle $\alpha$ has a value between about 20° and 100° and the constant $\tau$ has a value between about 0.8 and 0.95.

5. The antenna of claim 3 in which said feeder is a balanced line which twists 180° between the connections to successive dipoles.

6. A broadband unidirectional antenna comprising a balanced feeder line consisting of two closely spaced, straight and parallel conductors, a plurality of dipoles each consisting of two dipole elements, one of which elements is connected to one of said conductors, the other element being connected directly opposite the first to the other of said conductors, the elements of any dipole extending in opposite directions perpendicular to the plane determined by said conductors, consecutive dipole elements on each of said conductors extending in opposite directions, the ratio of the lengths of the elements in any two adjacent dipoles being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an element of any dipole in the antenna, $l_{(n+1)}$ is the length of an element in the adjacent smaller dipole and $\tau$ is a constant having a value less than $l$, the spacing between said dipoles being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the dipole having the element length $l_n$ and the adjacent larger dipole, $\Delta S_{(n+1)}$ is the spacing between the dipole having the element length $l_n$ and the adjacent smaller dipole, and $\tau$ has the significance previously assigned.

7. The antenna of claim 6 wherein $\tau$ has a value of about 0.8 to 0.95.

8. The antenna of claim 6 wherein said feeder line conductors are tubular.

9. An aerial system including at least one set of parallel dipoles spaced along and substantially perpendicular to the longitudinal axis of a two-conductor balanced feeder to which the halves of the dipoles are connected at their inner ends, said dipoles being of different electrical lengths increasing substantially logarithmically from the connected end of the feeder to the other end and the dipole feeder connections being crossed over one another between adjacent dipoles, the spacings between which also increase substantially logarithmically from said connected end to the other end.

10. An antenna system for wide-band use comprising a plurality of substantially parallel conducting dipole elements arranged in substantially collinear pairs, the opposite dipole elements of each pair constituting dipole halves, a two-conductor balanced feeder having one conductor connected to each of said elements at substantially the inner end thereof, each of said dipole halves in a pair being connected to a different feeder conductor, adjacent dipole elements being reversely connected to different conductors of the feeder, said dipole elements being selectively spaced along and substantially perpendicular to said feeder, the elements of each pair being of substantially equal length, adjacent dipole elements of different pairs differing in length with respect to each other by a substantially constant scale factor, the selective spacings between adjacent dipoles generally decreasing from one end of the feeder to the other with the greatest spacing being between the longest dipoles, and means to connect the feeder to an external circuit at substantially the location of the smallest of the dipole elements.

11. An antenna system for wide-band use comprising a plurality of substantially parallel conducting dipole elements arranged in substantially collinear pairs, the opposite dipole elements of each pair constituting dipole halves, a two-conductor balanced feeder having one conductor connected to each of said elements at substantially the inner end thereof, each of said dipole halves in a pair being connected to a different feeder conductor, adjacent dipole elements being reversely connected to different conductors of the feeder, said dipole elements being selectively spaced along and substantially perpendicular to said feeder, the elements of each pair being of substantially equal length, adjacent dipole elements of different pairs differing in length with respect to each other by a substantially constant scale factor, the selective spacings between the dipoles along the feeder differing from each other also by a substantially constant scale factor, the greatest spacing being between the longest dipoles, and means to connect the feeder to an external circuit at substantially the location of the smallest of the dipoles.

12. The aerial system of claim 11 in which said scale

factors have values within the range from about 0.8 to about 0.95.

13. An antenna system for wide-band use comprising an array of at least three linear substantially parallel conducting dipoles, each dipole being composed of two opposite substantially collinear conducting elements, a two-conductor balanced feeder having one conductor connected to each of said elements at substantially the inner end thereof, adjacent parallel dipole elements being reversely connected to a different conductor of the feeder, the two elements of each dipole being of substantially equal length and successive elements being of lengths which differ from one dipole to the next by a substantially constant scale factor within the range from about 0.8 to about 0.95, the dipoles being spaced from each other in a generally decreasing manner in the direction of decreasing element length, and means to connect the feeder conductors to an external circuit at substantially the location of the smallest dipole elements.

14. An antenna system for wide-band use comprising a minimum of three pairs of linear substantially parallel conducting elements arranged substantially coplanarly, each pair being substantially collinear and comprising the halves of a dipole, a two-conductor feeder connected to the inner ends of said collinear pairs of elements, adjacent parallel elements being connected to different conductors of the feeder so that the halves of the dipoles connect to different conductors of the feeder and adjacent dipoles are reversely connected, the halves of each dipole being substantially the same length, adjacent dipole elements being selectively spaced from each other along the feeder, the length of the successive dipole elements along the feeder decreasing in accordance with a substantially constant scale factor, each dipole and the feeder between it and the adjacent dipole constituting a cell, the dimension of the several cells measured from the point of connection of one dipole and the feeder to the outer end of the next smaller adjacent dipole also decreasing from one cell to the next in the direction of decreasing dipole length according to a substantially constant scale factor so that the combination of cells provides a substantially uniform wide-band response, and means to connect an external circuit to the feeder elements at substantially the location of the shortest of the dipoles.



15. An antenna system for wide-band use comprising a minimum of three pairs of substantially parallel and coplanar linear conducting elements arranged in substantially collinear pairs, each pair of elements comprising the halves of a dipole, a two-conductor feeder, one conductor of which is connected to each of said elements substantially at the inner end thereof, adjacent parallel elements being connected to different conductors of the feeder so that the halves of the dipoles connect to different conductors of the feeder and adjacent dipoles are reversely connected, the halves of each dipole being substantially the same length, adjacent dipole elements being selectively spaced from each other along the feeder, the lengths of the elements decreasing from one end of the feeder to the other substantially in accordance with a substantially constant scale factor within the range from about 0.8 to 0.95, each dipole and the feeder between it and the adjacent dipole constituting a cell, the cell dimension from the inner end of one dipole to the outer end of the next smaller adjacent dipole also generally decreasing from one cell to the next in the direction from the longer to the shorter dipoles so that the combination of cells provides a substantially uniform wide-band response, and means to connect an external circuit to the feeder elements at substantially the location of the shortest of the dipoles.


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HERMAN KARL SAALBACH, *Primary Examiner.*

GEORGE N. WESTBY, ELI LIEBERMAN, *Examiners.*

JFD EXHIBIT 2F.

Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 1

FIG 1b

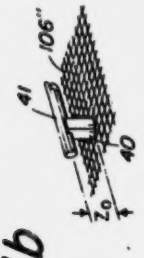



FIG 1a

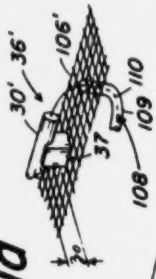
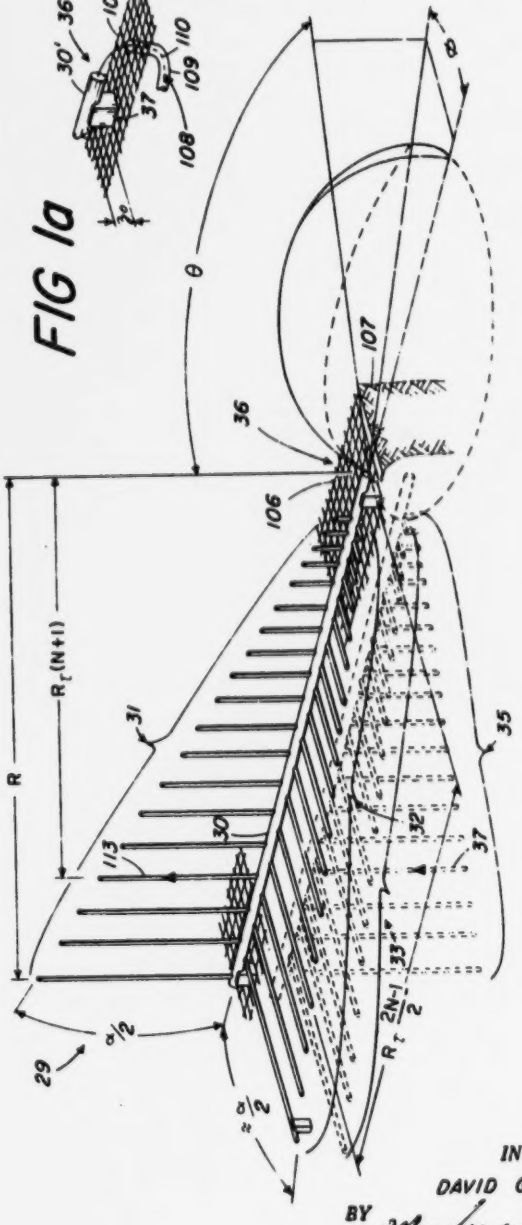



FIG 1

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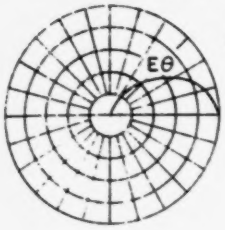
Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 2

FIG 2




SEE FIG 1 FOR DEFINITION OF ANGLES θ AND Φ

FIG 2a

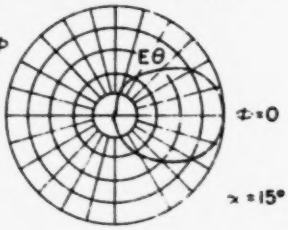



FIG 3

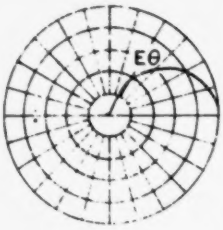



FIG 3a

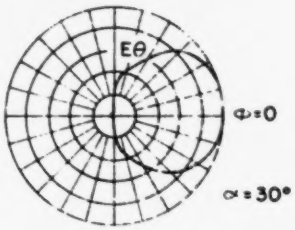



FIG 4

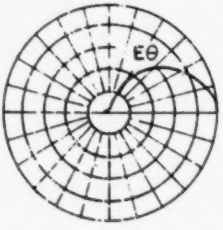
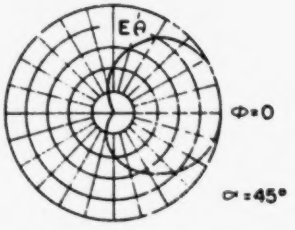



FIG 4a

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 3

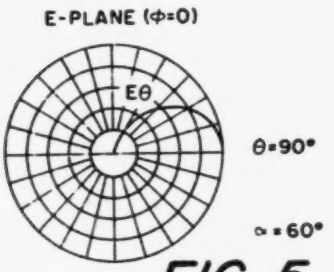



FIG 5

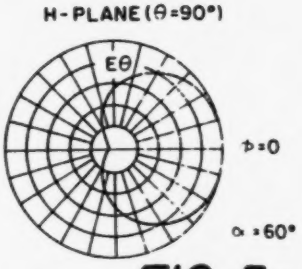



FIG 5a

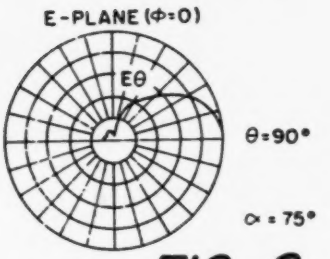



FIG 6

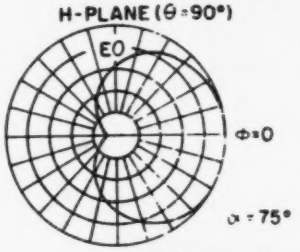
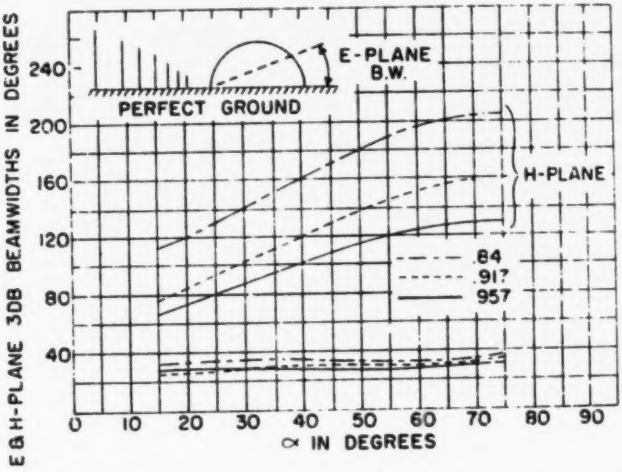



FIG 6a

FIG 7

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 4

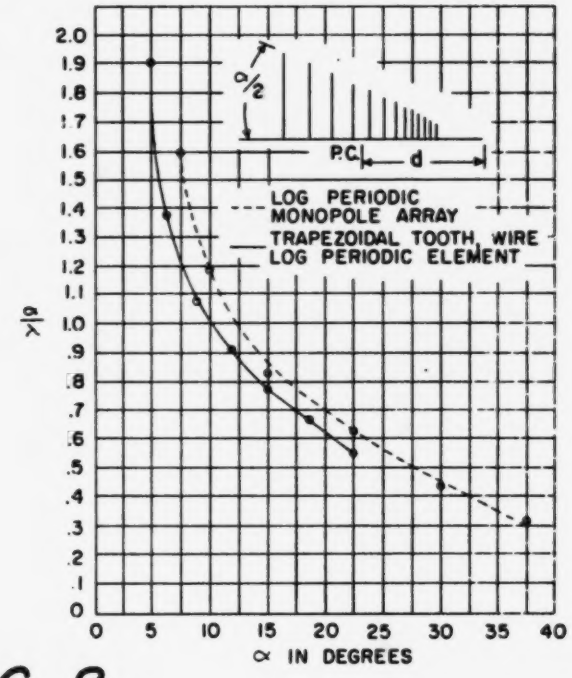
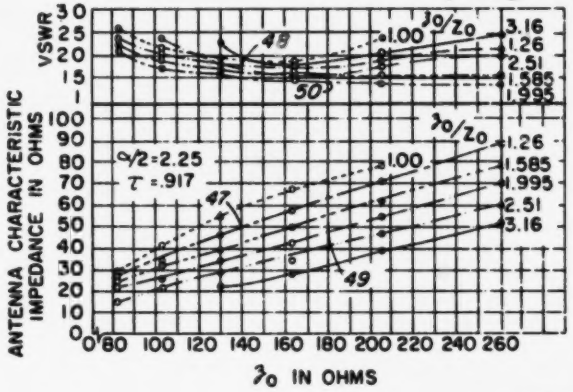



FIG 8

FIG 9

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVEP GROUND

Filed May 31, 1951 11 Sheets-Sheet 5

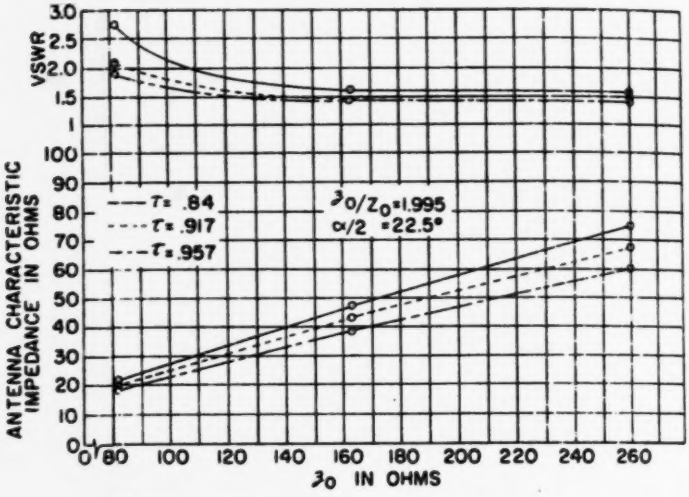
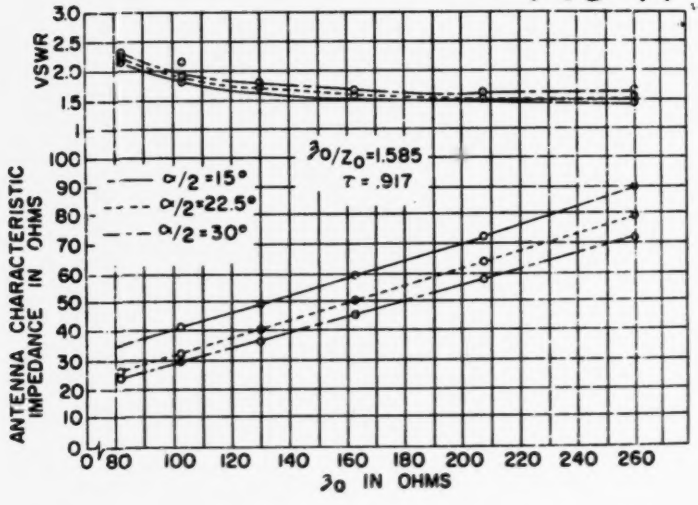



FIG 10

FIG 11

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

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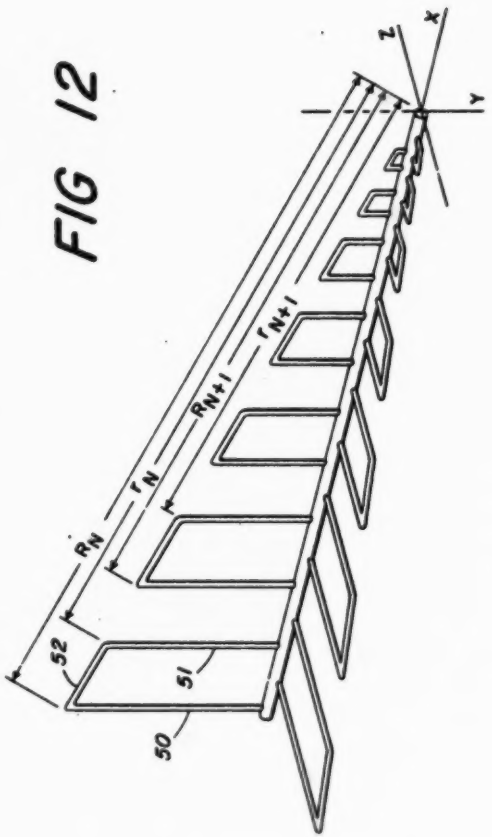
FIG 12




INVENTOR.
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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

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FIG 13

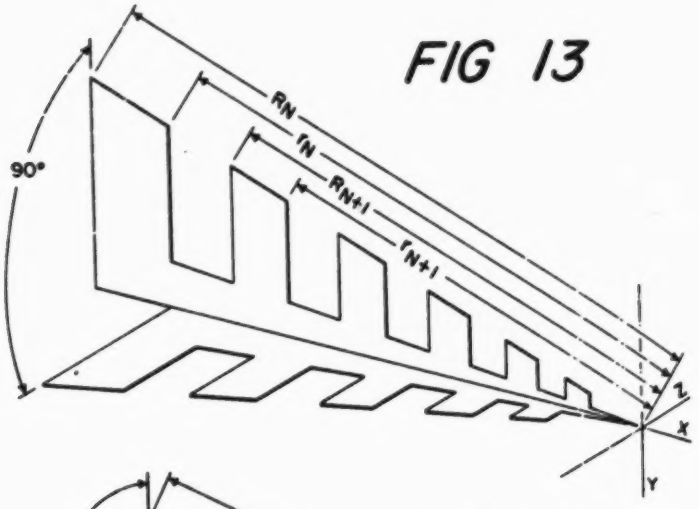



FIG 14

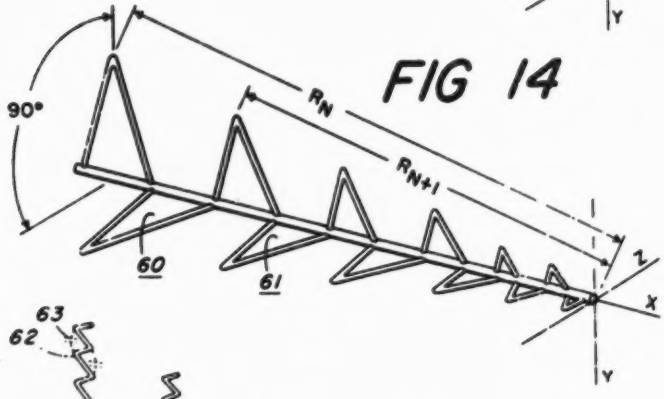
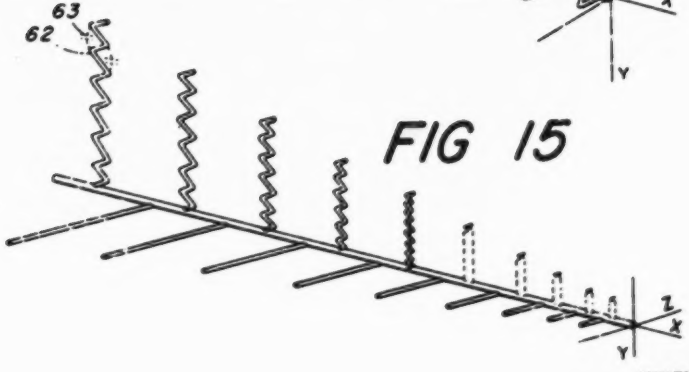



FIG 15

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA C"ER GROUND

Filed May 31, 1961 11 Sheets-Sheet 8

FIG 16

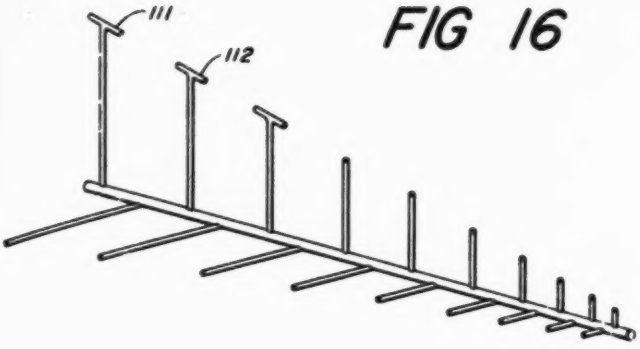
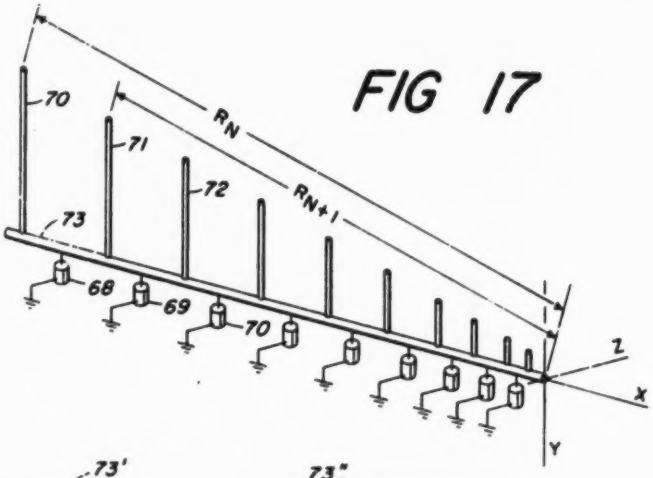



FIG 17



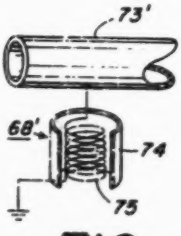




FIG 18

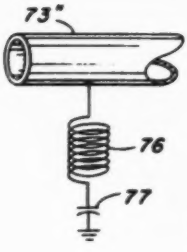



FIG 19

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 9

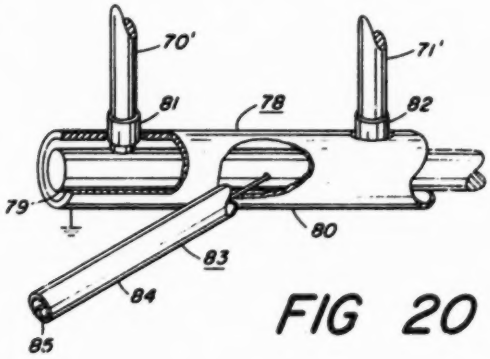


FIG 20

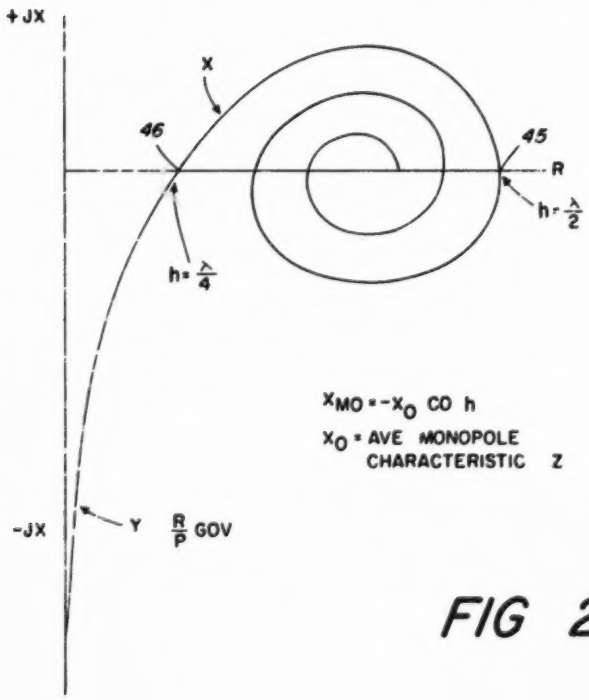


FIG 21

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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 10

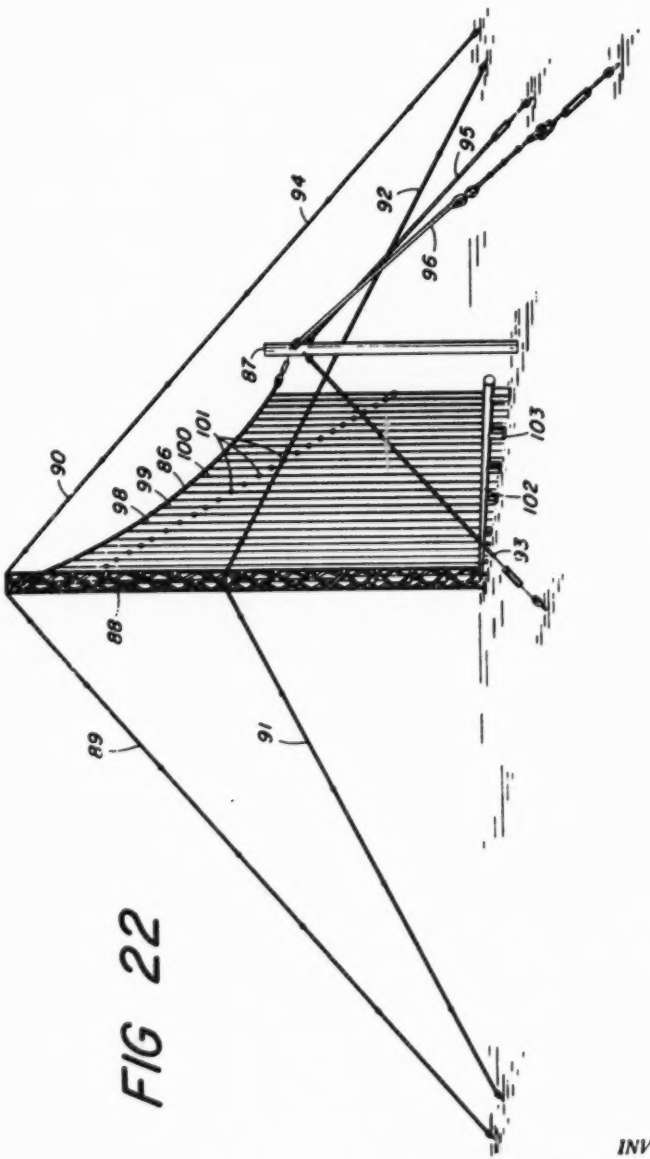


FIG 22

INVENTOR.
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Oct. 12, 1965 D. G. BERRY 3,212,094

VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

Filed May 31, 1961 11 Sheets-Sheet 11

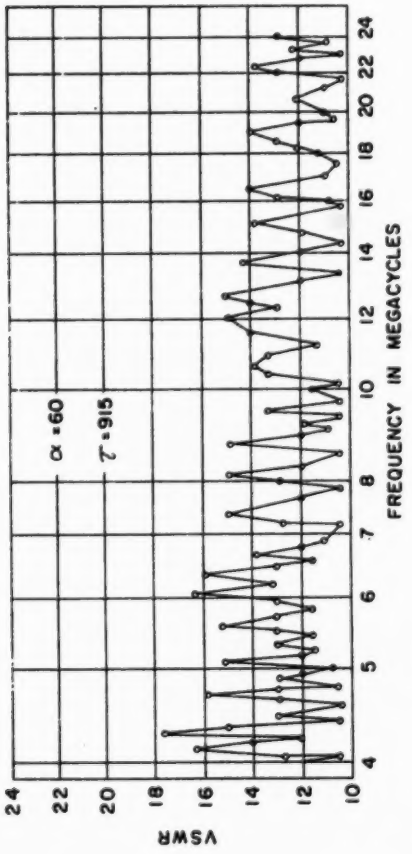


FIG 23

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United States Patent Office

3,212,094
Patented Oct. 12, 1965



3,212,094

# VERTICALLY POLARIZED UNIDIRECTIONAL LOG PERIODIC ANTENNA OVER GROUND

David G. Berry, Cedar Rapids, Iowa, assignor to Collins Radio Company, Cedar Rapids, Iowa, a corporation of Iowa

Filed May 31, 1961, Ser. No. 113,700
30 Claims. (Cl. 343—749)

This invention relates generally to logarithmic periodic antenna arrays and, more particularly, to logarithmic periodic antenna arrays in which one or more logarithmic periodic antenna elements are placed over a reflecting surface, such as ground, and the real antenna elements are fed against the reflected image elements, thus effecting a reduction in the number of actual antenna elements required in a given array.

Logarithmic periodic antennas, hereinafter sometimes referred to as log periodic antennas, are a recent development in the antenna art. Perhaps the most important feature of the log periodic antennas lies in their ability to maintain a constant radiation pattern over large frequency changes on the order of 10 or 20 to 1, or even greater. Such antenna systems (log periodic antenna systems) may be described generally as consisting of a plurality of individual antenna elements, each antenna element being generally triangular in shape, having a vertex, and being confined within an angle $\alpha$ extending from a vertex. A boom of conductive material is positioned along the bisector of the angle $\alpha$ and functions to supply electrical signals to the antenna elements, as well as to support said elements. Each antenna element is comprised of at least two radial sections, each section being generally triangular in shape with a common vertex and a common side, said common side being the boom referred to above. The outer side of each triangularly shaped radial section is defined by a radial line extending from the vertex at an angle $\alpha/2$ formed with respect to said center line or boom of the antenna element. Further, each radial section has a plurality of teeth comprised of elements which are positioned in a generally transverse manner with respect to the center line of the antenna element. Such teeth are all similar to one another in shape, but become progressively larger and spaced progressively farther apart as the distance from the common vertex increases. The above-mentioned size and spacing relationships may be expressed by stating that in a given radial section the radial distance from the vertex to a given point on any given tooth bears a constant ratio $\tau$ to the radial distance to a corresponding point in the adjacent tooth next farthest removed from the vertex than said given tooth. In the most general case, where each antenna element employs two radial sections lying in the same plane, the teeth of one of the radial sections are positioned opposite the gaps between the teeth of the other radial section. It is to be noted that throughout this specification a single tooth of an antenna radial section will sometimes be referred to as a monopole.

The log periodic antenna elements described in the preceding paragraphs may be arranged in many different combinations to perform desired functions. Usually, the antenna elements are employed in multiples of two, i.e., in pairs. For example, a pair of log periodic antenna elements may be arranged in such a manner that the vertices are near each other (but not quite touching), and which lie in the same plane. Such an arrangement is known in the art as a planar array of log periodic antenna elements. For a more detailed description of such structure, the reader's attention is directed to the following Patent Applications which are hereby incorporated by reference into the present specification: United States patent application, Serial No. 721,408, filed March 14, 1958, by Raymond H. DuHamel and Fred R. Ore and entitled "Logarithmically Periodic Antenna," now Patent No. 3,079,602; United States patent application, Serial No. 804,357, filed April 6, 1959, by Raymond H. DuHamel and David G. Berry, entitled "Unidirectional Frequency Independent Coplanar Antenna," now Patent No. 2,989,749; United States patent application, Serial No. 841,391, filed September 21, 1959, by Raymond H. DuHamel et al., entitled "Antenna Arrays," now Patent No. 3,059,234; United States patent application, Serial No. 841,400, filed September 21, 1959, by Raymond H. DuHamel et al., entitled "Broadside Antenna Arrays," now Patent No. 2,984,835; United States patent application, Serial No. 31,068, filed May 23, 1960, by David G. Berry, entitled "Unidirectional Circularly Polarized Antenna," now Patent No. 3,113,316.



It has been found that the cost of construction of the antenna arrays described in the preceding paragraphs, and in the applications incorporated herein by reference, has been quite high, especially in the lower frequency bandwidths. Such high cost is due primarily to the fact that the log periodic antenna arrays require a number of large antenna elements which are mounted in the air, usually many feet above the ground, on large masts. Structural difficulties are encountered in that the antenna elements usually consist of rather long dipole elements mounted on suitable booms. In the presence of wind or sleet the dipole elements function as cantilever levers and provide rather serious stresses and strains at the point of connection to the boom elements. Because of these problems the cost of the arrays is quite high.

One method that has been employed to simplify a log periodic antenna array has been to mount an antenna element over a reflecting surface, such as ground, with the vertex located near the reflecting surface and the remainder of the antenna element being slanted upwards. The radial antenna element is then fed against the image element produced in the reflecting surface. Such an arrangement obviously eliminates one-half of the antenna elements required and can be used to form either coplanar arrays, nonplanar arrays, or combination coplanar and nonplanar arrays with each antenna element of the array being fed against its image produced in the reflecting surface. A serious problem from the viewpoint of cost still remains, however. More specifically, this problem lies in the fact that the rear of the individual antenna elements, which is the heavy portion of the antenna elements (since the radiation occurs off the vertex which is regarded as the front of the elements), must be supported well above the ground surface. Such support again involves large supporting masts to support the booms of the individual antenna elements and also involves the cantilever action of the dipole elements on their supporting booms, as discussed hereinbefore, in the presence of wind or ice.

It is an object of the invention to provide a log periodic antenna array in which no supporting mast is required and in which the cantilever action of the individual monopole or dipole elements is minimized.

A further object of the invention is to provide a log periodic antenna array which is relatively inexpensive.

Another aim of the invention is the improvement of log periodic arrays, generally.

In accordance with a preferred form of the invention a single antenna element having two radial sections mounted at right angles to each other on the boom thereof is positioned so that the boom is parallel with, and just a small distance above, a reflective surface, such as the surface of the earth. The monopoles making up one of the radial sections are positioned vertically with respect

to the reflective surface and function as the radiating section to produce a vertically polarized electric field. The monopoles forming the second radial section are positioned parallel with respect to the ground surface and, because of their cooperation with their images produced in the reflecting surfaces, will function as sections of transmission lines instead of radiating elements. More specifically, the monopoles forming the second radial section will function as loading elements along the boom; said loading being a necessary requisite to radiation from the vertically positioned monopoles. It should perhaps be noted at this point that the current flow in the individual monopole elements positioned parallel to the reflecting surface is of opposite plurality to the current flow in its image monopole element produced in the reflecting surface. Since these two currents are in opposite directions, the radiating effect of each is cancelled out by the radiating effect on the other.

In another form of the invention the stubs may be replaced by other structures which will perform the same loading function. More specifically, such other structure may take the form of a resonator which consists of a helical winding enclosed within a cylinder; one end of the helical winding being connected to the boom at the geometric mean between the two adjacent vertical monopoles with the outer end of said winding floating and with the cylinder being connected to the ground surface. Such a resonator is constructed to resonate at the same resonant frequency as the stub it replaced.

In another form of the invention the stubs are replaced with a loading means comprised of an inductor and a capacitor connected in a series between ground potential and the geometric mean point of the boom between the two adjacent vertical monopole elements.

In accordance with another embodiment of the invention the boom of the antenna element can be a coaxial type structure with the vertical positioned monopoles being connected to the inner conductor of the coaxial structure through holes drilled in the outer conductor of the coaxial type structure. Appropriate means are provided to insulate the vertically positioned monopoles from said outer conductor. In this form of the invention the stubs are replaced by another coaxial type structure which has its inner conductor connected to the inner conductor of the boom and its outer conductor connected to the outer conductor of the boom.

In accordance with other features of the invention the various types of antenna radial sections may be employed. More specifically, there may be employed radial sections having vertical teeth formed of single rods, solid rectangularly shaped teeth comprised of sheets of metal, rectangularly shaped teeth formed of rods bent to form said rectangularly shaped teeth, and triangularly shaped teeth formed of a rod bent to fashion the triangularly shaped teeth.

The above-mentioned and other objects and features of the invention will be more fully understood from the following detailed description thereof when read in conjunction with the drawings in which:

FIG. 1 is a perspective view showing one form of the invention;

FIGS. 1*a* and 1*b* show blown-up views of the small segments of the main boom and a horizontally positioned monopole;

FIGS. 2 through 6*a* show radiation patterns in the H and E plane of the structure of FIG. 1 for various parameters thereof;

FIG. 7 is a curve showing variation in the E and H plane as functions of $\alpha$ and $\tau$;

FIG. 8 is a graph showing the variations of the phase center of the structure of FIG. 1 as a function of $\alpha$ and the variations of the phase center of log periodic antenna element having wire-formed trapezoidal teeth;

FIGS. 9, 10, and 11 are charts showing the variations of the over-all antenna impedance as functions of various parameters of the structure;

FIGS. 12, 13, 14, 15, and 16 show various forms of the invention;

FIGS. 17, 18, 19, and 20 show modifications of the invention wherein other impedances are substituted for the transmission stubs shown in prior figures;

FIG. 21 shows an impedance chart;

FIG. 22 shows a pictorial representation of an embodiment of the invention; and

FIG. 23 is a chart showing the variation in standing wave ratio with frequency of the structure of FIG. 22.

Referring now to FIG. 1, there is shown an antenna element which consists of a boom **30**, a radial element **29** including radiating monopoles **31**, and a set of stubs **32** which with their images **33** form sections of transmission lines. The entire structure shown in FIG. 1 is positioned a short distance above a reflecting surface **106**, which can be a copper screen laid on the surface of the ground **107**. The exact distance that the boom **30** is placed above ground is determined by several factors which will be discussed in more detail hereinafter. At this time it is perhaps sufficient to say that the characteristic impedance $z_0$ of the stub is the important factor and is in part controlled by the spacing of the boom from ground. As shown in dotted lines in FIG. 1, there is a mirrored image of the antenna element **29** reflected in the ground reflecting surface **36**. From an examination of the figure it will be seen that the real vertical monopoles **31** and the reflected vertical monopoles **35** function to produce a radiated electromagnetic field, whereas the real stubs **32** and the reflected stubs **33** function to cancel out any radiating effects on each other they might have had. Consider the function of the vertical monopoles **31** and their images **35** in detail. The current flow at any given time in a given vertical monopole **31** and its reflected monopole will be in the same directions. Such similarly phased currents will function to produce a single beam radiation pattern on the E plane, that is the vertical plane, off the apex **36** of the antenna structure. For the purposes of illustration, the instantaneous current flow in monopole **113** and the reflected monopole **37** is represented by arrows drawn on the monopoles.

The reflected instantaneous currents in the real stubs **32** and the reflected stubs **33** flow in opposite directions. However, since any real stub and its reflected image are positioned close together, side by side, and parallel with respect to each other, the radiation effects from each of the two elements function to cancel the radiation effects of the other.

The stubs **32** and the reflected image **33** thus become short sections of transmission line, each of which present an impedance to the transmission line formed by the boom **30** and its image, as follows:

$$-jz_0 \operatorname{Cot} Bl \qquad (1)$$

where $z_0$ is the characteristic impedance of the stubs and where $l$ is the length in wavelengths of a particular stub. The stubs are located at the geometric mean between the vertical monopoles, and the lengths of the stubs are such that their first resonance occurs at a frequency which has a ratio $\tau^{3/4}$ to the resonant frequency of the adjacent nearest vertical monopole next farthest removed from the vertex. As will be discussed later herein, the stubs may be replaced by lumped constant loading means. The entire array is fed by means of an underground coaxial cable **108** (see FIG. 1*a*) comprised of an outer conductor **109** connected to the copper screening **106'** and an inner conductor **110** connected to the boom **30'**. A generator (not shown) supplies its output to the coaxial cable **108**.

In FIG. 1*a* there is shown also a view of the relationship of the boom to ground. The boom **30'** is supported on a suitable support means **37** which is of an insulative material and which provides the desired physical spacing

of the boom 30' from the reflecting surface 106'. The characteristic impedance $Z_o$ of the boom 30' is determined in conventional manner by the diameter of the boom 30' and its physical distance from ground (surface 106'). It is to be noted that the blown-up view of FIG. 1*a* is taken at the front end of the antenna structure, that is, at the vertex 36.

In FIG. 1*b* there is shown a blown-up view of an end of one of the stubs and its relationship to the copper sheet 106". A spacing and supporting means 40 is employed to space the stub 41 a desired distance from surface 106". The diameter of the stub 41 and its physical spacing from the ground 38 determines its characteristic impedance $z_o$. Such characteristic impedances $Z_o$ and $z_o$ are impedances which are independent of frequency. In the case of a stub the particular impedance presented to the boom at a given frequency is given by Expression 1 as set forth hereinbefore.

At this point it is, perhaps, appropriate to note the impedance for the entire antenna structure, such impedance being defined by the Expression 2 below:

$$Z_{mo}\ (\text{monopole array}) = \frac{Z_o}{\sqrt{1+\frac{\sqrt{\tau}\tan\frac{\alpha}{2}}{1-\tau}\left(\frac{Z_o}{Z_{o(av)}}+\frac{Z_o}{z_o}\right)}} \quad (2)$$

Where

$Z_{mo}$ is the input characteristic impedance of the entire array

$z_o$ is the characteristic impedance of the stubs

$Z_o$ is the characteristic impedance of the transmission line (the boom)

$Z_{o(av)}$ is the average characteristic impedance of a monopole and is approximately equal to

$$60\left[ln\left(\frac{2h}{a}\right)-1\right]$$

$h$ is the monopole height

$a$ is the monopole radius

In Expression 2 the second term of the denominator

$$\frac{\sqrt{\tau}\tan\frac{\alpha}{2}}{1-\tau}\left(\frac{Z_o}{Z_{o(av)}}\right)$$

is the contribution of the vertical monopoles 31 to the overall input characteristic impedance.

The third term of the denominator of Expression 2

$$\frac{\sqrt{\tau}\tan\frac{\alpha}{2}}{1-\tau}\left(\frac{Z_o}{z_o}\right)$$

represents the contribution of the stubs to the over-all input characteristic impedance of the array. By examination of Expression 2 it can be seen how the characteristic impedance of the entire antenna array $Z_{mo}$ differs from the characteristic impedance of the boom 30. More specifically, if the impedance of the monopoles $Z_{o(av)}$ and the impedance of the stubs were to go to infinity, then the second and third term of the denominator would go to zero and drop out, leaving the following expression:

$$Z_{mo}=Z_o \quad (3)$$

which, of course, states that if the impedance of stubs and monopoles are removed from the structure, the remaining impedance is equal to $Z_o$, the characteristic impedance of the boom.

The operation or performance of the antenna array shown in FIG. 1 can best be described in qualitative manner inasmuch as the precise theory of the operation of such antenna is, at present, not thoroughly understood. Assume that a signal having a frequency near the midband of operation is supplied to the vertex of the antenna between ground potential and the boom 30 by coaxial cable (FIG. 1*a*) and launches a balanced TEM mode on the line which is loaded alternately with the shunt admittances of the stubs and the monopoles. Near the vertex of the structure the resonant frequency of the stubs will be considerably greater than the frequency of the generator so that the shunt admittances presented by the monopoles and stubs will be quite small and quite reactive. Consequently, the shunt admittances in this region will have comparatively little effect upon the transmission mode which will then travel along the boom with a velocity just a little less than that of light. As the transmission mode progresses further down the antenna boom the increasing admittances will affect it in an increasingly greater degree. Such phenomena will continue until a point on the antenna structure is reached at which one of the stubs is close to resonance and has a very large admittance with respect to the transmission line (boom) impedance characteristics. Such large admittance will occur when the term $Bl$ approaches 90° in the Expression 1. At this point almost all of the supplied energy will be either radiated or reflected back towards the generator and only a small amount of the energy (down roughly 30 or 40 db) will progress past this point. Consequently, the portion of the antenna beyond such point of resonance is of small consequence; i.e., at this particular frequency of operation.

As stated hereinbefore, the currents produced in the vertical monopoles cause radiation. The function of the open-circuited stubs is to adjust the phase and the amplitude of the currents of the vertical monopoles to produce a unidirectional radiation pattern. The log periodic arrangement of stubs and monopoles allows the radiation pattern (as well as the other characteristics of the antenna) to be substantially frequency independent. It is to be noted, again, at this point that it is not completely understood how the monopoles and the stubs co-act to produce the necessary phase relationships in the currents in the vertical monopoles to produce a unidirectional radiating field.

In FIGS. 2 through 6*a* there are shown the radiation patterns of the antenna element of FIG. 1 as a function of the angle $\alpha$ with a fixed $\tau$. The angle $\theta$ represents the angle of elevation, measured from a vertical line, at which the pattern was sampled and the angle $\phi$ represents the azimuth, measured from the line along which the boom lies, at which the pattern was sampled. It can be seen that the radiation in the E plane is substantially constant over a rather wide range of $\alpha$ angle values, but that the radiation pattern in the H plane increases substantially as the $\alpha$ angle increases.

In the chart of FIG. 7 there is shown graphically the half-power beam width formation as a function of both $\alpha$ and $\tau$. Although only one pattern is shown for each set of parameters, patterns at all frequencies in the bandwidth of the antenna will be substantially identical.

As indicated hereinbefore and as discussed in some detail, in United States patent applicaton, Serial No. 841,391, mentioned above, a number of antenna elements, such as the one shown in FIG. 1, may be arrayed together with a common vertex to form a more complex and versatile antenna system. Since such antenna elements would extend out radially from a common vertex, it is apparent that the phase centers of each of the antenna elements will not fall along a straight line if each of the antenna elements is identical in structure. The phase center is defined as that point in the antenna from which the radiated signal appears to radiate. Such phase center will vary with frequency. As described in the copending application, Serial No. 841,391, the various antenna elements may be stretched or shrunk to produce phase shifts in the radiated signal so that for any given frequency the phases of the signals radiated from each of the antenna elements are coincident along a straight line, thus providing for a plane wave front of maximum intensity, since

the vectorial sum of all of the radiated signals will be maximum under these conditions.

It should perhaps be noted, in passing, that the phase center at a given frequency does not usually coincide with the frequency represented by the length of the monopole at the phase center. In FIG. 8 there is shown in chart form the distance from the vertex 36 to the phase center in wavelengths as a function of the angle $\alpha/2$. As might be expected, the distance in wavelengths will decrease markedly as $\alpha/2$ increases.

The impedance of the antenna structure of FIG. 1 will now be discussed in some detail. The over-all antenna impedance can, perhaps, be best described by first determining the characteristic impedance of an antenna structure having specific parameters of $z_o$, $z_o/Z$, $\tau$ and $\alpha$. Then the standing-wave ratio with respect to such characteristic impedance can be determined.

Over a period of frequency the impedance, as plotted on the Smith chart of FIG. 21, progresses in a circular or elliptical path along the point around the real axis of abscissa. The characteristic impedance of the antenna is defined as the geometric mean of the highest (the point 45) and the lowest (the point 46) values of resistance intersected on this path during the period (and, of course, every other period). The standing-wave ratio is defined as a ratio of the maximum value of resistance at point 45 to the characteristic impedance. In FIGS. 9 through 11, (the lower group of curves in each figure), there is shown graphically the values of the characteristic impedance and the standing-wave ratio as a function of the parameters $z_o$, $z_o/Z_o$, $\alpha$ and $\tau$. From the curves of FIGS. 9, 10, and 11, it can be seen that a fairly large variation of characteristic impedance can be achieved with a quite good standing-wave ratio for a given value of $\alpha$ and $\tau$. The use of $\alpha$ and $\tau$ as criteria of good performance is important because $\alpha$ and $\tau$ are the two principal factors determinative of the shape of the antenna element and the number of monopoles required per unit length of the antenna. For example, in FIG. 9 assume that it is desired to have an antenna characteristic impedance of 50 ohms. Now, if the antenna is constructed so that the ratio of $z_o/Z_o$ is 1.26, it can be seen as such and that the curve representing such ratio will cross the 50-ohm antenna characteristic impedance level at point 47. Worded in another way, the foregoing sentence means that as the diameter of the stubs and their spacing from ground is varied so as to vary $z_o$, and as the diameter of the boom and its spacing from ground is varied so as to vary $Z_o$, but in a manner such that $z_o/Z_o$ is always equal to 1.26, then the over-all characteristic impedance of the antenna will be 50 ohms when $z_o$ is 140 ohms. It should, perhaps, be noted that the data for the charts of FIG. 9, and also of FIGS. 10 and 11, was obtained by conducting field tests on antennas having various sized stub diameters and boom diameters and processing such data to create the curve shown in FIGS. 9 to 11.

Referring now to the group of curves at the top of FIG. 9, and selecting the curve where the $z_o/Z_o$ ratio is 1.26, it can be seen that the standing-wave ratio is about 1.8, as shown at point 48. The standing-wave ratio can be improved, however, by selecting a $z_o/Z_o$ ratio of 1.995 which crosses the 50-ohm level at point 49 in the lower group of curves of FIG. 9. In the upper group of curves the standing-wave ratio can be seen to be about 1.45 at point 50, which is a considerable improvement compared to the standing-wave ratio obtained with a $z_o/Z_o$ ratio of 1.26. In FIG. 10 there is shown the variation obtained in antenna characteristic impedance when the ratio $z_o/Z_o$ and $\alpha$ are held constant and $\tau$ is varied. It can be seen that as a general rule the larger $\tau$ is, the lower the standing-wave ratio will be.

In FIG. 11 there is shown the variation of standing-wave ratio and antenna characteristic impedance when the ratio $z_o/Z_o$ and $\tau$ are held constant and when the angle $\alpha$ is varied. It can be seen that as $\alpha$ grows smaller the standing-wave ratio decreases somewhat.

It might facilitate an understanding of the charts of FIGS. 9, 10 and 11 to describe briefly some of the difficulties and techniques involved in securing a low standing-wave ratio at the input terminals of the antenna. As indicated hereinbefore, the actual length of both the stubs and the monopoles will vary somewhat from their electrical lengths. If the exact relationship between the electric lengths and the physical length of both the vertical monopoles and the stubs were known it would be possible to have angle $\alpha/2$ for both the monopoles and the stubs of such a value that the comparative electrical lengths of the two would always be in accordance with the geometric constant $\tau$. It is also to be noted that while the angle $\alpha/2$ is used both with respect to the monopoles and the stubs, that in actual practice these two angles might be somewhat different due to the fact that the ratio of the electrical length to physical length will not be quite the same for both the stubs and the monopoles. As a practical matter, the relationship between the electrical length and the actual length of the stubs can be quite accurately determined by analysis. However, electrical length of the monopoles cannot be so easily determined. To overcome this problem the following scheme was devised to determine experimentally the proper value of $\alpha$ associated with the stubs for a given $\alpha$ associated with the monopoles. This was done by constructing the antenna so that the $\alpha$ associated with the stubs was equal to the $\alpha$ associated with the monopoles. Then the $\alpha$ of the stubs was reduced until a standing-wave ratio at the input terminals of the antenna was reduced to the minimum value. By this method the antenna array was made as nearly frequency independent as possible and test data obtained for the curves of FIGS. 9, 10, and 11 was felt to be quite accurate.

In FIGS. 12 through 17 there are shown various modifications of the structure shown in FIG. 1. In FIG. 12 the ends of adjacent pairs of the monopoles and the stubs are joined together by conductive elements. For example, the monopoles 50 and 51 are joined together by transverse element 52. The principal advantage of this modification is one of mechanics. For example, if the monopoles and stubs are formed of rods, the rods can be bent to form the trapezoidal-shaped teeth, as shown in FIG. 2, which will have a degree of mechanical strength substantially greater than the individual monopoles.

The structure of FIG. 13 shows an antenna array employing solid teeth. Such solid teeth might be employed advantageously in circumstances where the antenna would be supported upon a wall, for example.

In FIG. 14 there is shown an antenna array employing triangularly shaped teeth. The principal advantage of this type of an array is greater structural strength, particularly where stiff rods are used to form the individual teeth. The stubs, such as 60 and 61, are also shown as being triangular in shape. Such triangular shape, however, for the stubs is primarily a matter of design and they could be straight rods, such as shown in the structure of FIG. 15, positioned at the geometric mean between adjacent ones of said triangular teeth, with an electrical length equal to the geometric mean of the electrical length of the adjacent teeth.

In FIG. 15 there is shown a structure which is very similar to the structure shown in FIG. 1. However, in FIG. 16 some of the monopoles are of a zigzag configuration which produces an effective lengthening of the electrical length of the vertical monopoles. More specifically, the zigzagging functions to introduce shunt capacitance along the monopole, which is represented generally by the broken line capacitors 62 and 63, which are in reality stray capacitances and not component capacitors. Normally, a dipole element will present a capacitive reaction to a signal having a frequency less than the resonant frequency of the dipole element. Thus, if

the capacitive reactance of the transverse dipole element can be reduced, the resonant frequency of the transverse dipole element will also be decreased. Since capacitive reactance is inversely proportioned to capacitance and since capacitances are added in parallel, it follows that the capacitive reactance of a transverse dipole element and thus the frequency of resonance will be decreased if shunt capacitance is created across the transverse dipole element. As indicated above, such shunt capacitance is created by the zigzag configuration of FIG. 15. In summary, such shunt capacitance will increase the apparent electrical length of monopole elements of FIG. 15, thus extending the lower frequency element of the lower antenna element without increasing the over-all size of the antenna element. For a more detailed discussion of the operational and constructural characteristics of the zigzag type monopole reference is made to United States patent application, Serial No. 63,372, filed October 18, 1960, entitled "Antenna" by Vito P. Minerva, now Patent No. 3,106,714.

Referring now to FIG. 16, there is shown another form of antenna element in which shunt capacitance is added to increase the electrical length of the individual monopoles. Specifically, the shunt capacitance is added by means of members, such as members 111 and 112, which are positioned generally transverse to the main portion of the monopole. The length of each of these transverse elements, such as 111 and 112, bear a ratio $\tau$ to the length of the element on the tooth-like element next farthest removed from the vertex. Thus, the length of element 112 bears the ratio $\tau$ to the length of element 111. For a more detailed discussion of the theory of operation of such transverse elements reference is herein made to United States patent application, Serial No. 63,299, filed October 18, 1960, by Raymond H. DuHamel et al. and entitled "Side Loaded Logarithmically Periodic Antenna," now Patent No. 3,127,611. The specific advantage of the structure of FIG. 16 is one of construction. With the structure of FIG. 16 it is possible to construct an antenna array somewhat in the manner shown in FIG. 22. It is apparent that the structure of FIG. 15 offers considerably more practical difficulty than that of FIG. 16, particularly when the type of supporting structure employed is that shown in FIG. 22.

As mentioned hereinbefore, the stubs may be replaced by lumped constant means of loading. There are several types of substitute loading means which may be employed in lieu of the stubs. For example, in FIG. 17 there is employed a series of resonators 68, 69, and 70, each of which may be placed at the geometric mean between the adjacent monopoles and each of which has a resonant frequency having an electrical length equal to the electrical length, multiplied by $\tau^{\frac{1}{2}}$ and at the same frequency, of the adjacent monopole next farthest removed from the apex. The foregoing sentences will, perhaps, be more clearly understood from the following example. As discussed hereinbefore, the electrical lengths of the dipoles 70 and 71 are somewhat different from their physical lengths. The radial distance $R_{n+1}$ of the monopole 71 bears a ratio $\tau$ to the radial distance $R_n$ of the monopole 70. Thus, the geometric mean between the monopoles 70 and 71 is equal to $\tau^{\frac{1}{2}}$ times the radial distance $R_n$. The electrical length of a monopole existing at this geometric mean (no such monopole is actually shown in FIG. 17), would be $\tau^{\frac{1}{2}}$ times the electrical length of the monopole 70. The electrical length of such a hypothetical monopole represents a quarter wavelength of a particular frequency. The resonator 68, which is shown in more detail in FIG. 18, has a resonant frequency equal to the aforementioned particular frequency. Similarly, the resonant frequency of the resonator 69 corresponds to the resonant frequency of a monopole located at the geometric mean between monopoles 71 and 72. The structure of the resonator is well-known in the art and will not be described herein. It should be sufficient to point out that the resonator 68' of FIG. 18 is comprised of a helix 75 of a conductive material having its upper end connected to the boom 73', also of conductive material, and having its lower end floating free. Positioned around the helix 75 is a cylinder 74, also of a conductive material, and being connected to ground potential. The particular resonant frequency of a given resonator is determined by the physical parameters of the helix and the cylinder in a manner well-known in the art.

In FIG. 19 there is shown an alternative means for providing loading along the boom 73", such alternative means consists of an inductor 76 and a capacitor 77, which form a series circuit having a resonance equal to the resonant frequency of a hypothetical monopole located at the geometric means between the adjacent monopoles. The principal advantage of the structure of FIG. 19 over that of FIG. 18 is lower cost. However, this advantage only exists at relatively small power levels. If higher power outputs are desired the cost of the capacitor becomes very large inasmuch as it must be an air capacitor in order to withstand the high power levels. The structure of FIG. 18, on the other hand, is readily adapted to handle large power requirements.

Referring now to the structure of FIG. 20, there is shown a third means which can be employed as a substitute for the stubs of FIG. 1, for example. The structure of FIG. 20 comprises a boom 78 which corresponds to the boom 73 of FIG. 17. The boom 78 of FIG. 20, however, is different from the boom of FIG. 17 in that boom 78 is really a large coaxial type structure comprising an inner conductor 79 and an outer conductor 80. The individual vertical monopoles, such as 70' and 71' are electrically connected to the inner conductor 79 through apertures provided therefor in the outer conductor 80. Insulating spacing means, such as spacers 81 and 82, are provided to electrically insulate the monopoles, such as 70' and 71' from the outer conductor 80 of the boom 78'. The loading means consists of another coaxial type arrangement 83 which comprises an outer conductor 84 and an inner conductor 85. The inner conductor 85 is connected to the inner conductor 79 of the boom 78 and the outer conductor 84 is connected to the outer conductor 80 of the boom 78. The outer conductors 80 and 84 of the boom and of the loading stub 83 are grounded. More specifically, the boom 78 is layed upon a conductive ground reflecting surface in such a manner that the stubs, such as stub 83, extend outwardly and parallel to said ground surface. An image of the structure will then exist in reflective ground surface and the input signal is applied across the input conductor 79 of the boom 78 and ground potential in a suitable manner, similar to that shown in FIG. 1*a*.

Referring now to FIG. 22, there is shown a view of an actual construction of an antenna, as shown in FIGS. 18–20. A supporting cable 86 is supported between pole 87 and tower 88. Guy wires 89, 90, 91, 92, 93, 94, 95, and 96 support the pole 87 and the tower 88. The individual monopole elements are supported from the tie wires, such as tie wires 98, 99, and 100, which in turn are supported from the main cable 86. Insulating means, such as insulating means 101, function to provide a means of physically connecting the upper end of the monopoles to the short supporting tie wires, such as tie wire 100, without making electrical contact therewith. The bottom ends and the vertical monopoles are secured to a boom 102 which is supported on the ground by support spacers, such as spacer 103.

The loading between the vertical monopoles is accomplished by lumped constants which cannot be seen in detail in the figure, but which are positioned along the boom 102. Such lumped constants can be of the type shown in FIGS. 18, 19, or 20. In the particular structure of FIG. 21 resonators of the type shown in FIG. 18 are employed. The structure shown in FIG. 21 has an operating characteristic over the bandwidth of from 4 to 24 mc.

as shown in the curve of FIG. 23, in which the standing wave ratio is plotted against the frequency. The constants of α and τ of FIG. 21 are, respectively, 60° and .915.

It is to be noted that the forms of the invention shown and described herein are but preferred embodiments thereof and that other configurations of log periodic antenna elements may be employed in a similar manner over ground surface to produce a radiation pattern which is substantially frequency independent over large bandwidths, without departing from the spirit or scope of the invention.

I claim:

1. An antenna system comprising a log periodic radial section having a conductive boom and a plurality of tooth-like elements extending outwardly from said boom in a common plane, said radial section having an apex and being generally tri-angular in shape with the tooth-like elements having their outer ends defined by an angle α/2 measured from said boom, the radial distance from said apex to a given point on any of said tooth-like elements bearing a constant ratio τ to the radial distance of the corresponding point on the tooth-like element next farthest removed from said vertex, a substantially flat grounded surface, said radial section being positioned normal to and over said substantially flat grounded surface which is constructed to produce a reflection of said radial section therein, said radial section being further positioned with the boom just above and substantially parallel with said flat grounded surface, and impedance loading means positioned along said boom between said tooth-like elements.

2. An antenna system in accordance with claim 1 in which said impedance loading means is comprised of a plurality of rod-like elements extending outwardly from said boom at the geometric midpoint between adjacent ones of said tooth-like elements, all of said impedance loading means lying in a common plane substantially parallel with said flat grounded surface, each of said impedance loading means coacting with its image in said flat grounded surface to form a transmission line stub having a resonant frequency whose wavelength is equal to four times the electrical length, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest from the vertex of said radial section.

3. An antenna system in accordance with claim 1 in which each of said impedance loading means consists of a resonator, said resonator comprising a conductive helix having one terminal thereof connected to said boom and a cylinder of conductive material surrounding said helix and connected to said flat grounded surface, each of said helices being connected to the geometric midpoint between adjacent tooth-like elements and each of said resonators constructed to have a resonant frequency whose wavelength is equal to four times the electrical wavelength, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest removed from the vertex of the radial section.

4. An antenna system in accordance with claim 1 in which said impedance loading means comprises a series arrangement of an inductor and a capacitor connected between said flat grounded surface and the geometric midpoint between adjacent tooth-like elements, each series circuit being tuned to a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest removed from said vertex of said radial section.

5. An antenna system in accordance with claim 1 in which said boom comprises a coaxial type structure including a first inner conductor and a first outer conductor enclosing said inner conductor, said tooth-like elements being connected to said inner conductor through said outer conductor, said load impedance means each comprising a second coaxial type structure including a second outer conductor and second inner conductor, said second inner conductor being connected to said first inner conductor and said second outer conductors being connected to said first outer conductor, each of said second coaxial cables extending outwardly from said boom, said first and second outer conductors being electrically connected to said flat grounded surface, each of said coaxial stubs being constructed to have a resonant frequency whose wavelength is equal to four times the electrical length multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest removed from said vertex.

6. An antenna system in accordance with claim 1 in which each of said tooth-like elements consist of a single rod-like element extending outwardly from said boom.

7. An antenna system in accordance with claim 6 in which said impedance loading means is comprised of a plurality of rod-like elements extending outwardly from said boom at the geometric midpoint between adjacent ones of said tooth-like elements, all of said impedance loading means lying in a common plane substantially parallel with said flat grounded surface, each of said impedance loading means coacting with its image in said flat grounded surface to form a transmission line stub having a resonant frequency whose wavelength is equal to four times the electrical length, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest from the vertex of said radial section.

8. An antenna system in accordance with claim 6 in which each of said impedance loading means consists of a resonator, said resonator comprising a conductive helix having one of the terminals thereof connected to said boom and a cylinder of conductive material surrounding said helix and connected to said flat grounded surface, each of said helices being connected to the geometric midpoint between adjacent tooth-like elements and each of said resonators being constructed to have a resonant frequency whose wavelength is equal to four times the electrical wavelength, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest removed from the vertex of the radial section.

9. An antenna system in accordance with claim 6 in which said impedance loading means comprises a series arrangement of an inductor and a capacitor connected between said flat grounded surface and the geometric midpoint between adjacent tooth-like elements, each series circuit being tuned to a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest removed from said vertex of said radial section.

10. An antenna system in accordance with claim 6 in which said boom comprises a coaxial type structure including a first inner conductor and a first outer conductor enclosing said first inner conductor, said tooth-like elements being connected to said first inner conductor through said first outer conductor, said load impedance means each comprising a second coaxial type structure including a second outer conductor and second inner conductor, said second inner conductor being connected to said first inner conductor and said second outer conductors being connected to said first outer conductor, each of said second coaxial cables extending outwardly from said boom, said first and second outer conductors being electrically connected to said flat grounded surface, each of said second coaxial stubs being constructed to have a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{1/2}$ and at the same frequency, of the tooth-like element next farthest removed from said vertex.

11. An antenna system in accordance with claim 1 in which each of said tooth-like elements consist of a trapezoidal-shaped element extending outwardly from said boom.

12. An antenna system in accordance with claim 11 in which said impedance loading means is comprised of a

plurality of rod-like elements extending outwardly from said boom at the geometric midpoint between adjacent ones of said tooth-like elements, all of said impedance loading means lying in a common plane substantially parallel with said flat grounded surface, each of said impedance loading means coacting with its image in said flat grounded surface to form a transmission line stub having a resonant frequency whose wavelength is equal to four times the electrical length, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from the vertex of said radial section.

13. An antenna system in accordance with claim 11 in which each of said impedance loading means consists of a resonator, said resonator comprising a conductive helix having one of its terminals connected to said boom and a cylinder of conductive material surrounding said helix and connected to said flat grounded surface, each of said helices being connected to the geometric midpoint between adjacent tooth-like elements and each of said resonators being constructed to have a resonant frequency whose wavelength is equal to four times the electrical wavelength, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from the vertex of the radial section.

14. An antenna system in accordance with claim 11 in which said impedance loading means comprises a series arrangement of an inductor and a capacitor connected between the flat grounded surface and the geometric midpoint between adjacent tooth-like elements, each series circuit being tuned to a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from said vertex of said radial section.

15. An antenna system in accordance with claim 11 in which said boom comprises a coaxial type structure including a first inner conductor and a first outer conductor enclosing said inner conductor, said tooth-like elements being connected to said inner conductor through said outer conductor, said load impedance means each comprising a second coaxial type structure including a second outer conductor and second inner conductor, said second inner conductor being connected to said first inner conductor and said second outer conductor being connected to said first outer conductor, each of said second coaxial cables extending outwardly from said boom, said first and second outer conductors being electrically connected to said flat grounded surface, each of said coaxial stubs being constructed to have a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from said apex.

16. An antenna system in accordance with claim 1 in which each of said tooth-like elements consist of a triangularly shaped tooth extending outwardly from said boom.

17. An antenna system in accordance with claim 16 in which said impedance loading means is comprised of a plurality of rod-like elements extending outwardly from said boom at the geometric midpoint between adjacent ones of said tooth-like elements, all of said impedance loading means lying in a common plane substantially parallel with said flat grounded surface, each of said impedance loading means coacting with its image in said flat grounded surface to form a transmission line stub having a resonant frequency whose wavelength is equal to four times the electrical length multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest from the vertex of said radial section.

18. An antenna system in accordance with claim 16 in which each of said impedance loading means consists of a resonator, said resonator comprising a conductive helix having one of its terminals connected to said boom and a cylinder of conductive material surrounding said helix and connected to said flat grounded surface, each of said helices being connected to the geometric midpoint between adjacent tooth-like elements and each of said resonators being constructed to have a resonant frequency whose wavelength is equal to four times the electrical wavelength, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from the apex of the radial section.

19. An antenna system in accordance with claim 16 in which said impedance loading means comprises a series arrangement of an inductor and a capacitor connected between said flat grounded surface and the geometric midpoint between adjacent tooth-like elements, each series circuit being tuned to a resonant frequency whose wavelength is four times the electrical length, multiplied $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from said apex of said radial section.

20. An antenna system in accordance with claim 16 in which said boom comprises a coaxial type structure including a first inner conductor and a first outer conductor enclosing said first inner conductor, said tooth-like element being connected to said first inner conductor through said first outer conductor, said load impedance means each comprising a second coaxial type structure including a second outer conductor and second inner conductor, said second inner conductor being connected to said first inner conductor and said second outer conductor being connected to said first outer conductor, each of said second coaxial cables extending outwardly from said boom, said first and second outer conductors being electrically connected to said flat grounded surface, each of said second coaxial stubs being constructed to have a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from said apex.

21. An antenna system in accordance with claim 1 in which each of said tooth-like elements of said radial section is formed of a rod-like element, the portion of said rod-like element extending outwardly from said boom being telesoped upon itself to form a zigzag configuration substantially uniformly about a straight line.

22. An antenna system in accordance with claim 21 in which said impedance loading means is comprised of a plurality of rod-like elements extending outwardly from said boom at the geometric midpoint between adjacent ones of said tooth-like elements, all of said impedance loading means lying in a common plane substantially parallel with said flat grounded surface, each of said impedance loading means coacting with its image in said flat grounded surface to form a transmission line stub having a resonant frequency equal to four times the electrical length, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest from the apex of said radial section.

23. An antenna system in accordance with claim 21 in which each of said impedance loading means consists of a resonator, said resonator comprising a conductive helix having one of its terminals connected to said boom and a cylinder of conductive material surrounding said helix and connected to said flat grounded surface, each of said helices being connected to the geometric midpoint between adjacent tooth-like elements, and each of said resonators being constructed to have a resonant frequency whose wavelength is equal to four times the electrical wavelength, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next farthest removed from the apex of the radial section.

24. An antenna system in accordance with claim 21 in which said impedance loading means comprises a series arrangement of an inductor and a capacitor connected between the flat grounded surface and the geometric midpoint between adjacent tooth-like elements, each series circuit being tuned to a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{\frac{1}{4}}$ and at the same frequency, of the tooth-like element next

farthest removed from said apex of said radial section.

25. An antenna system in accordance with claim 21 in which said boom comprises a coaxial type structure including a first inner conductor and a first outer conductor enclosing said inner conductor, said tooth-like elements being connected to said inner conductor through said outer conductor, said load impedance means each comprising a second coaxial type structure including a second outer conductor and second inner conductor, said second inner conductor being connected to said first inner conductor and said second outer conductor being connected to said first outer conductor, each of said second coaxial cables extending outwardly from said boom, said first and second outer conductors being electrically connected to said flat grounded surface each of said coaxial stubs being constructed to have a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{1/4}$ and at the same frequency, of the tooth-like element next farthest removed from said apex.

26. An antenna system in accordance with claim 1 in which each of said tooth-like elements comprises a transverse member at the outer end thereof, the length of any of said transverse members bearing the ratio $\tau$ to the length of the transverse member on the tooth-like element next farthest removed from said vertex.

27. An antenna system in accordance with claim 26 in which said impedance loading means is comprised of a plurality of rod-like elements extending outwardly from said boom at the geometric midpoint between each of said tooth-like elements, all of said impedance loading means lying in a common plane substantially parallel with said flat grounded surface, each of said impedance loading means coacting with its image in said flat grounded surface to form a transmission line stub having a resonant frequency whose wavelength is equal to four times the electrical length, multiplied by $\tau^{1/4}$ and at the same frequency, of the tooth-like element next farthest from the apex of said radial section.

28. An antenna system in accordance with claim 26 in which each of said impedance loading means consists of a resonator, said resonator comprising a conductive helix having one of its terminals connected to said boom and a cylinder of conductive material surrounding said helix and connected to said flat grounded surface, each of said helices being connected to the geometric midpoint between adjacent tooth-like elements and each of said resonators being constructed to have a resonant frequency whose wavelength is equal to four times the electrical wavelength, multiplied by $\tau^{1/4}$ and at the same frequency, of the tooth-like element next farthest removed from the apex of the radial section.

29. An antenna system in accordance with claim 26 in which said impedance loading means comprises a series arrangement of an inductor and a capacitor connected between said flat grounded surface of the geometric midpoint between adjacent tooth-like elements, each series circuit being tuned to a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{1/4}$ and at the same frequency, of the tooth-like element next farthest removed from said apex of said radial section.

30. An antenna system in accordance with claim 26 in which said boom comprises a coaxial type structure including a first inner conductor and a first outer conductor enclosing said inner conductor, said tooth-like elements being connected to said first inner conductor through said first outer conductor, said load impedance means each comprising a second coaxial type structure including a second outer conductor and second inner conductor, said second inner conductor being connected to said first inner conductor and said second outer conductor being connected to said first outer conductor, each of said second coaxial cables extending outwardly from said boom with said first and second outer conductors being electrically connected to said flat grounded surface, each of said second coaxial stubs being constructed to have a resonant frequency whose wavelength is four times the electrical length, multiplied by $\tau^{1/4}$ and at the same frequency, of the tooth-like element next farthest removed from said apex.

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JFD EXHIBIT 3A.

Aug. 30, 1955 J. M. KANE 2,716,703

TELEVISION ANTENNA

Filed May 15, 1952

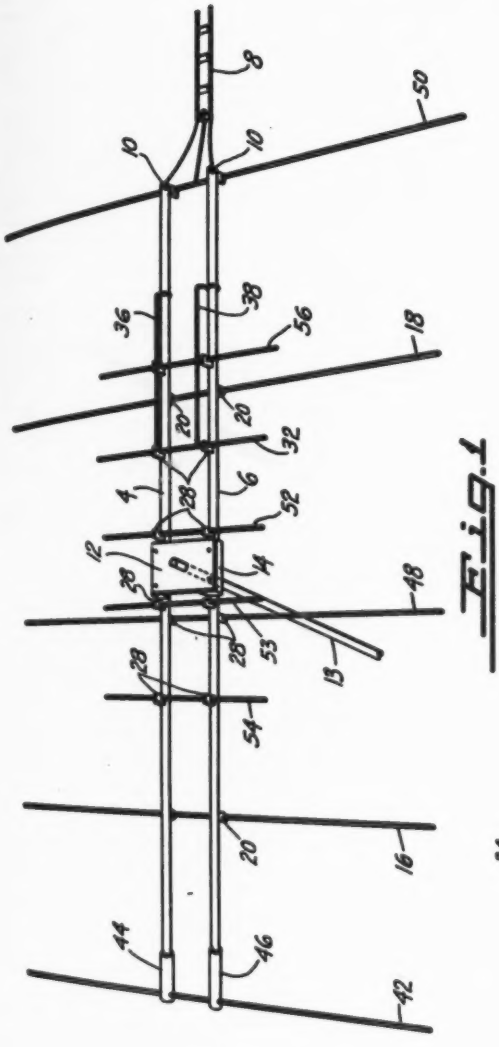


Fig. 1

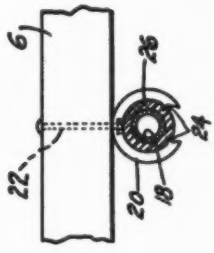


Fig. 2

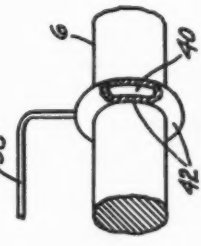


Fig. 3

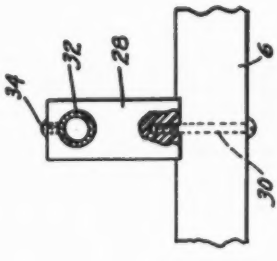


Fig. 4

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2,716,703

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1

2,716,703

# TELEVISION ANTENNA

James M. Kane, Los Gatos, Calif.

Application May 15, 1952, Serial No. 287,902

1 Claim. (Cl. 250—33.51)

This invention relates to a parasitic array of the Yagi type. More particularly, it relates to an antenna which is suitable for use in fringe area television reception of a number of channels.

It is one object of the present invention to provide a multiple band antenna which gives a high gain and high signal strength making it suitable for use in television fringe areas.

Another object of this invention is to provide an antenna which is suitable for multiple band reception wherein the elements for the different bands are supported only by the transmission line and wherein the transmission line is of such length that it provides a matching stub for the various bands resulting in a low standing wave ratio.

Another object of this invention is the arrangement of a multiple band antenna in such a manner that the elements for one band do not interfere with the reception from another band.

Still another object of this invention is to provide a highly directional antenna which will pick up a minimum of stray noise which might interfere with television reception.

Another object of this invention is to provide a television antenna which is strong, relatively light in weight and simple to manufacture.

A further object of this invention is to provide a highly directional antenna with high gain with broad frequency response, so that it will pass a complete television channel even in fringe areas.

Still another object of this invention is to provide an antenna having loose coupling between the driven elements and the transmission line said loose coupling tending to minimize stray pick-up and aid in the impedance match between the driven elements and the transmission line.

In the drawings forming a part of this application there is illustrated a preferred specific embodiment of my invention wherein the antenna is designed for use on channels 4, 5 and 7 as they are now designated by the Federal Communications Commission. It will be obvious to those skilled in the art that the same principles may be embodied in antennas suitable for reception of any desired channels and that more than three channels may be combined in a single antenna. In the description of the invention frequent reference will be made to the receiving properties of the antenna but it is obvious that the same principles may be embodied in a transmitting antenna.

Turning now to the drawings which form a part of this application there is shown in Figure 1 a perspective view of my improved television antenna.

In Figures 2 there is shown a detailed view of the method of coupling the driven element on channels 4 and 5 to the transmission line.

In Figure 3 is shown a detailed view of the method of coupling the driven element for channel 4 to the transmission line.

Figure 4 is a detailed view of the method of supporting

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all the parasitic elements and the driven element for channel 7 on the transmission line.

Referring now to the drawings by reference characters, there is shown in Figure 1 a television antenna having two parallel spaced bars designated 4 and 6 which serve both as a transmission line and as a support for the elements of the antenna. Bars 4 and 6 may be suitably made of thin walled aluminum tubing having an outside diameter of 1 inch and spaced 12 inches. Other suitable dimensions may be used, such as 1.25 inch tubing spaced 7.75 inches on centers. With these particular dimensions, the bars 4 and 6 constitute a transmission line having an impedance of slightly over 400 ohms. Thus, the transmission line consisting of bars 4 and 6 provides a good impedance match to conventional open wire transmission line 8 which has size 18 copper wires spaced 1 inch between center. Fastening means 10 are provided at one end of the transmission line for coupling to the open wire line 8. The impedance match is sufficiently close to permit ordinary plastic insulated line ("Twin Lead") to be used instead of the air insulated line illustrated.

The bars 4 and 6 are supported and held in their spaced relationship by a center section 12 which is preferably placed at the center of balance of the completed antenna and which provides a convenient way of fastening the antenna to a mast 13. Center section 12 may be made of plastic or metal but is suitably made with the center section of metal with plastic, or other insulating material 14 at each end thereof. The plastic ends 14 are provided with suitable means for fastening bars 4 and 6 to the center section 12 and for insulating the bars from the center section 12.

Both the driven and parasitic elements are supported at right angles to the bars 4 and 6 as is shown in the drawings.

In the embodiment shown, the antenna has three driven elements. The driven element for channel 5 is designated 16 and the driven element for channel 4 is designated 18. The element 16 is 70 inches long while the element 18 is 80 inches long. Thus these elements resonate in approximately the center of channels 5 and 4 respectively. These elements as well as the other elements to be described are suitably made from ½ inch O. D. aluminum tubing, although other suitable metals may be used.

The method of fastening these two driven elements to the bars 4 and 6 is shown in detail in Figure 2. The method consists of a U-shaped clamp 20 of spring metal which is attached to one of the transmission line elements 6 by means of a screw 22 or other suitable device. The clamp 20 has tangs 24 at the outer edges of the U which tend to lock the element into place. The element 18 is surrounded by a suitable insulator such as polyethylene 26. Thus the driven elements 16 and 18 are not directly connected to the transmission line but are insulated therefrom; the clamp 20 together with the insulation 26 and the element 18 constitutes a capacitor giving capacity coupling between the driven element and the transmission line. The capacitance of such a coupling is about 10 mmfd.

A different method is used for fastening the driven element for channel 7 and also the parasitic elements for all channels to the transmission line. This method is illustrated in Figure 4 and consists of an insulating block of plastic 28 connected by means of a screw 30 to the transmission line 6 and having a hole therein to accommodate the element 32. The element 32 may be held in place by means of a screw 34.

The driven element 32 is insulated from the transmission line by the insulator 28 and is connected to the transmission line through matching sections designated 36 and 38. The method of coupling the matching sections 36 and 38 to the transmission line is shown in Figure 3 and

consists of a metallic ring 40 covered with a plastic material 41. Preferably the ring is made from flattened tubing. The dimensions of this connection are so selected that a connector has a capacity of about 10 mmfd; the element 32 is connected to the transmission line capacitively only.

Having now described the driven elements of the array, the parasitic elements will be described. Located at the front of the antenna is the director 42 for channel 5. The director is 67 inches long and is spaced 29 inches (0.2 wave-length) from the channel 5 driven element 16. It will be noted that the director 42 is mounted on the transmission line by means of wooden rods 44 and 46. These wooden rods serve as insulators for the element 42 and are 8 inches in length. This leaves 21 inches of the transmission lines 4 and 6 ahead of the driven element 16, said lengths acting as matching stubs to match the driven element 16 to the transmission line. The wooden rods 44 and 46 may be painted with aluminum paint, thereby constituting a resistance element. Such a resistance tends to "swamp" any currents traveling from the back to the front of the antenna. Without such a terminating resistance, any reflected waves picked up from the opposite direction would be reflected back into the transmission line and cause a ghost image. In extreme fringe areas, the resistance may be omitted. Instead of painting the rods, a resistor may be fastened across the front of bars 4 and 6. A valve of 200 to 400 ohms is suitable.

The element 48 is 77 inches long and is mounted 33 inches (0.2 wavelength) from the elements 16 and 18. The element 48 serves as a director for driven element 18 and as a reflector for driven element 16. The element 16 also serves as a director for driven element 18. Mounted at the rear of the antenna is element 50 which is 84 inches long and spaced 33 inches from the element 18. The element 50 acts as a reflector for driven element 18.

Thus, the channel 5 driven element 16 has a director 42 and a reflector 48 and is provided with a matching open stub which is 21 inches long to match it to the transmission line. The channel 4 driven element 18 has two director elements 16 and 48 and one reflector 50. That portion of the transmission lines 4 and 6 lying in front of the driven element 18 constitutes about ½ wave length at the channel 4 frequency and assists in matching the channel 4 driven element to the line.

The channel 7 elements are preferably mounted on the opposite side of the bars 4 and 6 from the elements for channels 4 and 5, as shown. The channel 7 driven element 32 is 31.2 inches long and is insulated from the transmission line as shown; it has three director elements 52, 53 and 54 each of which is 30 inches long. The director element 52 is mounted 13 inches (0.2 wavelength) from the element 32 and in turn the element 53 is mounted 13 inches in front of element 52 and element 54 is mounted 13 inches in front of element 53. The reflector for channel 7 is the element 56 which is 33 inches long and mounted 13 inches behind the driven element 32.



As has been previously mentioned, the driven element 32 is insulated from the transmission lines 4 and 6 at its point of support and is coupled to the transmission line by the matching lines 36 and 38 which in turn are capacitatively coupled to the transmission lines. The elements 36 and 38 are about 28 inches long. The length of the electrical path from the channel 7 driven element 32 through the connecting lines 36 and 38 to the channel 4 driven element 18 is about 45 inches. This constitutes about ¼ wave length for channel 4 and an odd multiple of a ¼ wave length, i. e. ¾ wave length, for channel 7. This prevents there being interaction between the two elements which would result in one driven element shorting out the other.

By capacitatively coupling the driven elements to the transmission lines there is a minimum interference between the various driven elements which are coupled to the transmission lines. Further, the capacity coupling is such that it offers little resistance to the passage of the high frequency television signal but offers a high resistance to the passage of lower frequencies, such as ignition noise. Thus, by capacitatively coupling the elements to the line one secures a high signal strength together with a high attenuation of lower frequency noise.

It will be noted that the spacing between any driven element and its parasitic elements is about 0.2 wavelength. By using this separation the Q of the antenna is kept low, giving a broad response to pass on entire television channel.

The antenna of the present invention is a system or method whereby multiple complete antennas may be coupled through capacitances to a common transmission line.

I claim:

An antenna for high frequency use having in combination a spaced rigid transmission line, said transmission line having at right angles thereto more than one driven element, each of said driven elements being loosely coupled to the transmission line, and parasitic elements insulated from said transmission line, said rigid transmission line furnishing the sole support for the driven and parasitic elements, and wherein the spacing of one of said driven elements on the transmission line acts as a shorted matching stub for another of said driven elements on said transmission line.

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JFD EXHIBIT 3B.

Nov. 3, 1964 A. F. WICKERSHAM, JR., ET AL 3,155,976

BROADBAND STRAIGHT LADDER ANTENNA WITH TWIN WIRE BALANCED FEED SUPPLIED VIA INTEGRAL UNBALANCED LINE

Filed Aug. 31, 1959 3 Sheets-Sheet 1

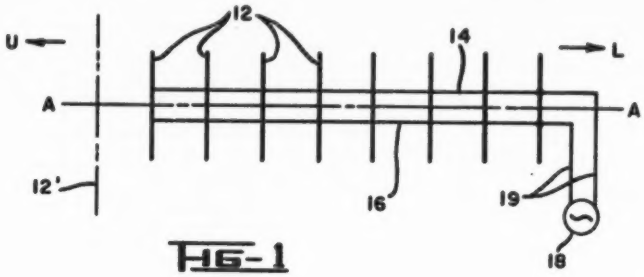


FIG-1

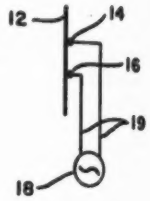


FIG-1A

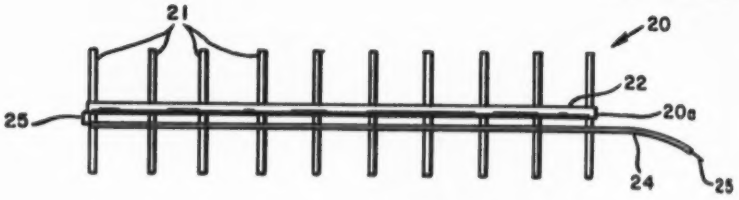


FIG-2

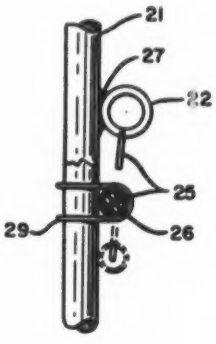


FIG-4

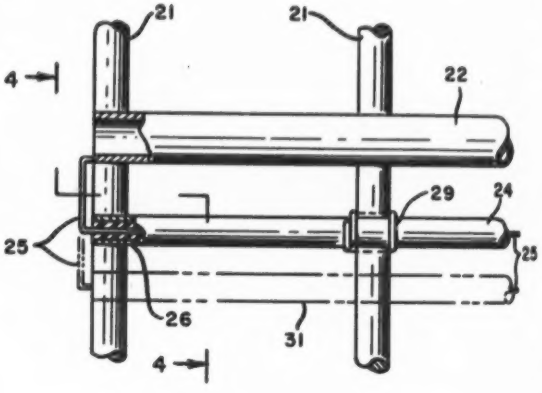


FIG-3

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Filed Aug. 31, 1959 3 Sheets-Sheet 2

FIG-6

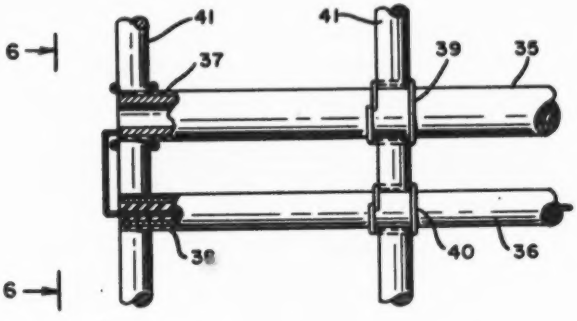


FIG-5

FIG-8

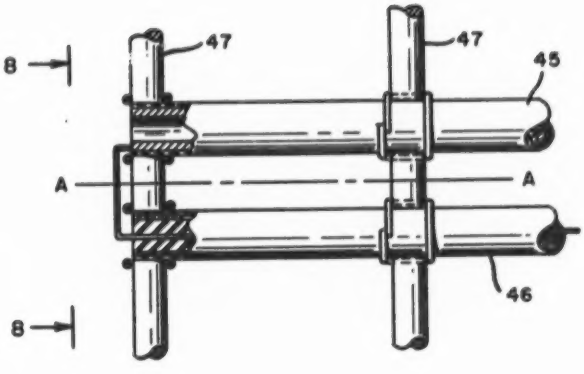


FIG-7

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BROADBAND STRAIGHT LADDER ANTENNA WITH TWIN WIRE BALANCED FEED SUPPLIED VIA INTEGRAL UNBALANCED LINE

Filed Aug. 31, 1959 3 Sheets-Sheet 3

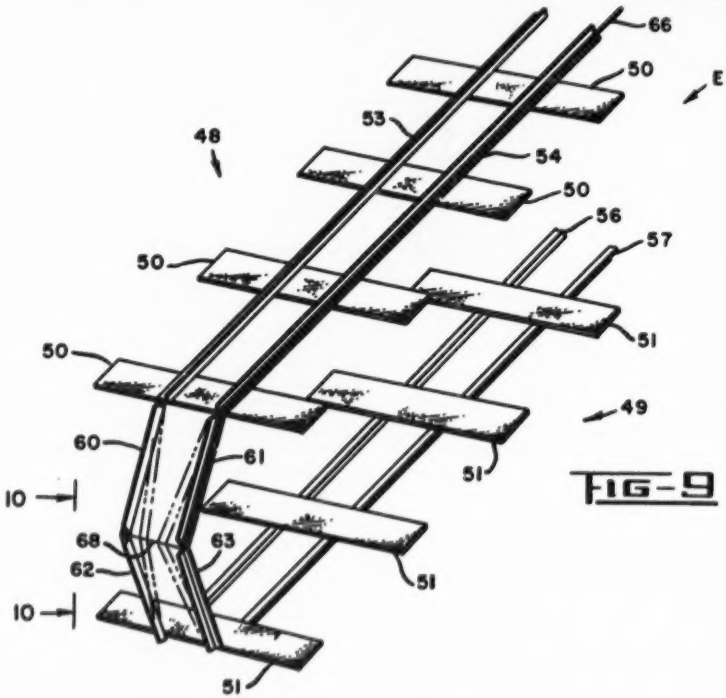


FIG-9

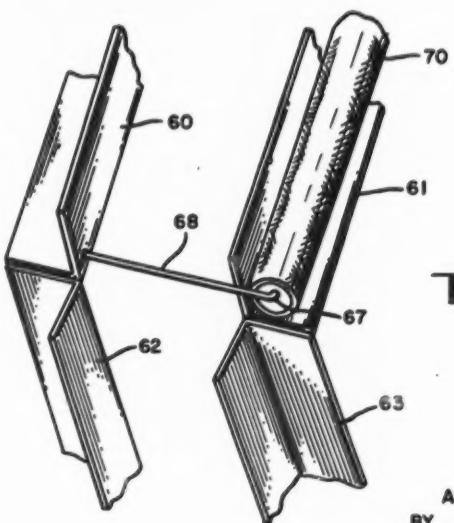


FIG-10

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United States Patent Office

3,155,976
Patented Nov. 3, 1964

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3,155,976

# BROADBAND STRAIGHT LADDER ANTENNA WITH TWIN WIRE BALANCED FEED SUPPLIED VIA INTEGRAL UNBALANCED LINE

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Filed Aug. 31, 1959, Ser. No. 837,005
5 Claims. (Cl. 343—814)

This invention relates to antennas, and in particular to a broadband end-fire antenna resembling the Yagi-Uda type.

The well-known Yagi-Uda antenna, called a "Yagi," is one of the simplest and most compact high-gain antennas known in the art. However, it has a high gain only over a very narrow band of frequencies, in the order of plus or minus 1½% of the operating frequency for a 1 db drop from maximum gain. The usefulness of the antenna is therefore limited to narrow band applications.

The present invention is concerned with improvement of the operating bandwidth of the Yagi-type antenna while preserving its compactness and structural simplicity. Briefly, we have provided an antenna comprising several parallel radiating elements aligned in a row and equally spaced apart, and a twin wire feed line which traverses these several elements for the length of the row. The array is descriptively called a straight-ladder antenna. The length and spacing of the radiating elements may be the same as used in conventional Yagi designs. The twin wire feed line may be electromagnetically coupled to the radiating elements and in one embodiment of the invention comprises the antenna backbone members, called the "booms." A coaxial line extends alongside or inside one of the booms for the full length of the antenna. The center conductor of the coaxial line is connected to the end of the opposite boom which, in effect, becomes an extension of the center conductor. In one embodiment the outer conductor of the coaxial cable may of itself be, physically and electrically, one of the booms. The booms, then, constitute a twin wire feed.

In another embodiment, two such ladder antennas are stacked and joined at one end and are fed in parallel by a single coaxial line. The gain for this two-bay array is greater than that of the single-bay configuration. In both the single and two-bay arrays, the operating bandwidth is about four times that of the conventional Yagi antenna.

A primary object of our invention is the provision of a compact broadband end-fire antenna.

Another object is the provision of a modified Yagi-type antenna having an operating bandwidth substantially greater than that of the conventional Yagi antenna.

A further object is the provision of a broadband end-fire antenna which can be directly fed from an unbalanced line.

Another object is the provision of a straight-ladder type antenna having an input impedance which is readily and conveniently adjustable.

These and other objects of our invention will become apparent from the following description of preferred embodiment thereof, reference being had to the accompanying drawings in which:

FIGURES 1 and 1–A are schematic plan and end views, respectively, of a straight-ladder antenna and twin wire feed system embodying our invention.

FIGURE 2 is a plan view of a straight-ladder antenna in which the twin wire feed lines comprise the antenna boom and a juxtaposed coaxial cable.

FIGURE 3 is the enlarged partially cut-away end portion of the antenna of FIGURE 2 showing the connection of the center conductor of the coaxial line to the boom.

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FIGURE 4 is a section taken along line 4—4 of FIGURE 3.

FIGURES 5 and 6 are views similar to FIGURES 3 and 4, respectively, showing a modified form of the antenna feed.

FIGURES 7 and 8 are plan and end views, respectively, of another form of antenna feed.

FIGURE 9 is a perspective view of a modified form of the invention comprising a two-bay array of the straight-ladder type antenna.

FIGURE 10 is an enlarged view of a portion of FIGURE 9 showing the junction of the two bays and connection between the coaxial line to the boom.

Referring now to the drawings, an antenna embodying our invention is shown schematically in FIGURE 1 and comprises an array of elements **12** which are substantially identical in size and length, and which are equally spaced apart, parallel to each other, and perpendicular to and symmetrical about the antenna axis A—A. In accordance with our invention, electromagnetic energy is fed to the antenna by means of a twin wire transmission line comprising laterally spaced conducting lines **14** and **16** which extend across the elements **12** parallel to the antenna axis for the full length of the antenna. Conductors **14** and **16** may be intertwined about the radiating elements, so as to be in contact with opposite sides of adjacent elements, or may extend along the same side of the elements as shown in FIGURES 1 and 1–A. One or both of conductors **14** and **16** may be insulated from the radiating elements **12**, but satisfactory results also have been obtained when both conductors **14** and **16** are in direct electrical contact with each element **12**. When the antenna is used for transmitting, it is energized by a source **18** of high frequency having output lines **19** connected in parallel to lines **14** and **16**. If the antenna is used in a receiving system, a receiver replaces the source **18**. It will be understood, therefore, that the term "feed lines" as applied to conductors **14** and **16** comprehends the function of receiving energy from as well as delivering energy to the elements **12**, which elements either intercept or radiate the energy depending upon the use.

The general antenna configuration and feed system therefor shown in FIGURE 1 differs from the conventional Yagi antenna in that the former omits the exciter element and may omit the reflector element of the Yagi and has instead an array of elements that are essentially director elements. The distributed feed afforded by the twin wire transmission line operates in two ways to broaden the operating frequency of the antenna. First, the input impedance of the antenna, as seen at the terminals of lines **19**, remains uniform over the wider frequency band so that the problem of matching the antenna to the line is solved without resorting to line balancing devices (baluns) which are frequency sensitive. Secondly, the distributed feed, as opposed to excitation of one element as in the Yagi design, has the effect of producing a stable uniform radiation pattern over the wider frequency range. The directivity and gain of the straight-ladder antenna are about the same as that of the Yagi.

It should be noted that the direction of radiation of the straight-ladder antenna undergoes a sharp reversal as the frequency of the electromagnetic energy is swept over the operating range. (This is a reversal within as little as 0.12% change in frequency and without deterioration of the quality of the beam.) At the lower end of the operating range, the radiation is in the direction of the arrow L in FIGURE 1 and as the frequency is increased, energy radiates in the direction of the arrow U. If unidirectional radiation over the band is desired, one or more end elements **12'** having an increased length indicated by the broken lines may be added to the array so as to function as a reflector.

A preferred embodiment of the twin wire feed line for the straight-ladder antenna is shown in FIGURE 2 wherein the antenna 20 has radiating elements 21 supported on a central boom 22 and energy is transmitted to the antenna (when used as a transmitter) by means of a coaxial line 24 juxtaposed to the boom and extending parallel thereto across the radiating elements for the length of the antenna. The coaxial line 24 joins the antenna assembly at the input end 20a and its center conductor 25 is connected directly to the end of boom 22 opposite from the input end. Either the boom or the outer conductor of the coaxial line may be insulated from the radiating elements, although substantially the same operating characteristics are attainable when both the boom and the coaxial outer conductor are directly electrically connected to the elements 21. The outer conductor 26 of cable 24 forms one of the twin wire feed lines, and the boom, which is essentially an extension of the coaxial inner conductor, is the other feed line. The input impedance of the antenna as seen at the input end of the coaxial line is determined in part by the lateral spacing between the boom and the coaxial line, and conveniently may be matched to the feed line by adjustment of that spacing as suggested in FIGURES 3 and 4 in phantom lines.

Boom 22 is a rigid member made of conducting material, may be tubular as shown, and is the common support for the several radiating elements 21 which are secured to it as by welding 27, see FIGURE 4. The coaxial cable 24 may be intertwined on opposite sides of successive radiating elements or may extend along one side of the elements, as shown. Spring wire clamps, one of which is shown at 29, may be used to hold the cable in position. This clamp also permits adjustment of the spacing between the coaxial line and the boom for impedance matching purposes, as described above. In the embodiment shown in FIGURES 3 and 4, outer conductor 26 of the coaxial cable is directly connected to each of the radiating elements 21. It is not necessary to insulate elements 21 from either the outer conductor or the boom since this direct electrical connection does not cause a short at radio frequencies.

The straight-ladder antenna described above has an efficiency (ratio of realized gain to observed directivity) which is identical to that of the conventional Yagi antenna but has a bandwidth at least four times as great as the Yagi. While the impedance of the straight-ladder antenna does vary with large excursions in frequency, nevertheless, the voltage standing wave ratio is 1.1 or less over the frequency range for units which have been built and tested.

FIGURES 5 and 6 illustrate a modification of former arrangement wherein both the boom 35 and the coaxial cable 36 are insulated from radiating elements 41. The boom has external insulation 37 and, similarly, cable 36 is insulated by rubber-like sheath 38. Spring clamps 39 and 49 hold the radiating elements 41 to the boom and cable, respectively. Energy is derived from both sections of the twin line by electromagnetic coupling. The overall input impedance of the antenna can be controlled by varying the thickness of the dielectric insulation between the elements 41 and boom 35 and between elements 41 and cable 36, as well as by varying the distance of separation of boom 35 and cable 36 from one another.

In another form of the invention shown in FIGURES 7 and 8, the boom 45 and cable 46 are insulated from the radiating elements 47, as in FIGURES 5 and 6, but here the boom and cable are the same diameter. Also, these two parts of the twin feed line are symmetrically disposed about the center line A—A of the antenna. This configuration has the advantage that the radiated beam is more nearly colinear with the center line of the antenna. In other respects, performance is substantially the same as with the antennas of FIGURES 3 and 5.

Another form of our invention shown in FIGURES 9 and 10 wherein two straight-ladder type antennas 48 and 49 are stacked with their respective longitudinal axes parallel and spaced apart and with their respective transversely disposed radiating elements 50 and 51 having axes lying in successive equally spaced planes substantially perpendicular to the longitudinal axes. In the embodiment shown in the drawings, antenna 48 has a pair of structural members 53 and 54, such as angle iron strips, extending parallel to and spaced from each other and to which the several radiating elements 50 are secured. Similarly, co-extensive laterally spaced structural parallel members 56 and 57 provide support for the radiating elements 51 of antenna 49. Members 53 and 54 are mechanically and electrically connected and secured at one end to members 56 and 57, respectively, by means of interconnecting members 60, 61, 62 and 63. The radiating elements 50 and 51 take the form of rectangular plates made of conducting material, secured as by welding to the structural members.

The two antenna bays are fed from the open end E to the right as viewed in FIGURE 9, by a coaxial line 65 which extends along structural members 54 and 61 to the junction of the latter with member 63, see FIGURE 10. At this point, the coaxial line terminates but its center conductor 67 is connected by conductor 68 to the opposite member 60. The outer coaductor 70 of the cable is in direct electrical contact with members 54 and 61, and since members 61, 63 and 57 are electrically connected, the effect is that members 56 and 57 of the lower bay are parallel fed twin wire feed lines. In order to improve the match of the antenna to the line, members 60, 61, 62 and 63 may be disposed to converge toward the centered feed point as indicated in broken lines in FIGURE 9. This in effect functions as a transformer and holds the voltage standing wave ratio to a minimum. The two-bay array of FIGURE 9 provides in the order of 3 db additional gain over that of a single array and has an end-fire radiation pattern that is substantially uniform over a wide frequency range.

Dimensions and characteristics of antennas of the type described above which have been successfully tested and operated are:

| | Figure 2 | Figure 9 |
|---|---|---|
| Elements 21 | Rods | Plates. |
| Number | 13 Directors, 2 Reflectors. | 4 in each Bay. Total 8. |
| Length | Dir.—3.31". Ref.—3.94". | 10.25". |
| Diameter or Thickness | 0.125" | 0.163". |
| Width | | 0.675". |
| Spacing | 2.5" | 5". |
| Length of Boom 22 | 36.8" | 22". |
| Spacing of Antenna Axes | | 10.25". |
| Design Frequency | 1,450 mc | 400 mc. |
| Operating Bandwidth (1 db down from max. gain) | Appx. ± 2% | Appx. ± 5%. |
| VSWR (max. over bandwidth) | 1.1 | 2.0. |

Modifications and changes may be made to the above described embodiments of our invention without departing from spirit and scope of the invention. The appended claims define the elements of novelty of the invention.

We claim:

1. A high frequency end-fire antenna having an axis and comprising a plurality of conducting elements arranged in a common plane and extending parallel to each other, said elements being axially spaced from each other, and means for feeding electromagnetic wave energy to said conducting elements comprising a coaxial cable and a conducting member, both extending axially and being electromagnetically coupled to said elements for the full length of the antenna, said cable having an outer conductor and an inner conductor, said inner conductor being directly electrically connected to said conducting member at one end of the antenna, and energy input means coupled to said coaxial line at the opposite end of the antenna for transmitting energy to said elements.

2. A high frequency end-fire antenna having an axis and comprising a plurality of straight conducting elements arranged in a row in a common plane and extending parallel to each other transversely of and generally symmetrically about said axis, said elements being axially spaced from each other, and transmission line means for feeding electromagnetic wave energy to said conducting elements comprising an axially extending conducting member traversing said elements for the full length of the row, a coaxial cable having a length thereof juxtaposed to and coextensive with said member and terminating at one end of said row, said cable having an inner conductor and an outer conductor, said member and the outer conductor of said cable being electromagnetically coupled to said elements, means connecting said inner conductor at said one end of the cable to the adjacent end of said member, said cable and said member being laterally spaced apart, and electromagnetic apparatus connected to the other end of said coaxial cable for feeding energy to said elements.

3. A high frequency end-fire antenna having an axis and comprising a plurality of straight conducting elements of equal length arranged in a row and in a common plane parallel to each other and extending transversely of and generally symmetrically about said axis, said elements being equally axially spaced from each other, and transmission line means electromagnetically coupled to said conducting elements comprising an axially extending conducting member traversing said elements for the full length of the row, a coaxial cable having a length thereof juxtaposed to and coextensive with said member and terminating at one end of said row, said cable having an inner conductor and an outer conductor, means connecting said inner conductor at said one end of the cable to the adjacent end of said member, said cable and said member being laterally spaced apart, and electromagnetic apparatus connected to the other end of said coaxial cable for feeding energy to said elements.



4. An antenna having an axis and comprising an array of axially spaced continuous transverse elements in a common plane containing said axis, and a pair if juxtaposed axially extending feed lines coextensive with said array and disposed immediately adjacent to and coupled to said elements, one of said feed lines comprising an unbalanced transmission line.

5. An antenna having an axis comprising an array of axially spaced continuous transverse elements in a common plane containing said axis, and a pair of juxtaposed axially extending feed lines coextensive with said array and disposed immediately adjacent to and coupled to said elements, one of said feed lines comprising a coaxial cable.


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JFD EXHIBIT 3C.

Sept. 13, 1949. C. F. VALACH 2,481,801

ANTENNA ARRAY

Filed Dec. 8, 1945 3 Sheets-Sheet 1

Fig. 1.

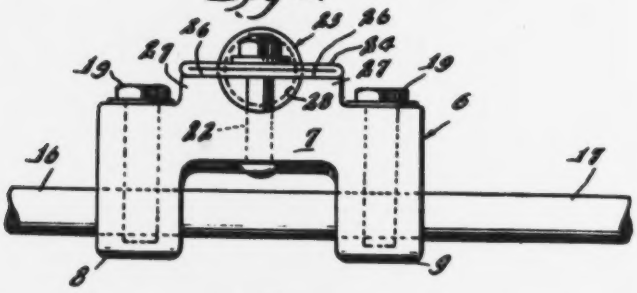



Fig. 2.

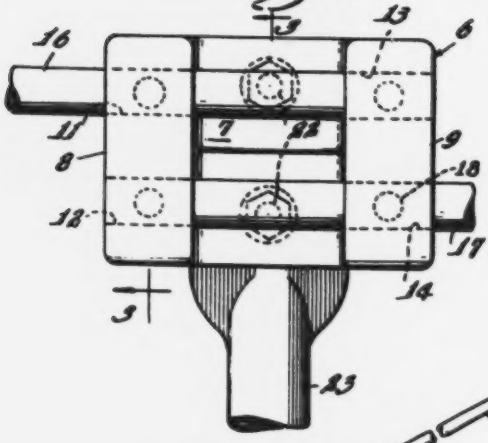



Fig. 3.

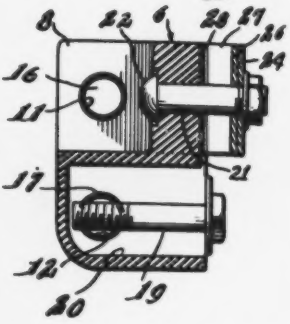
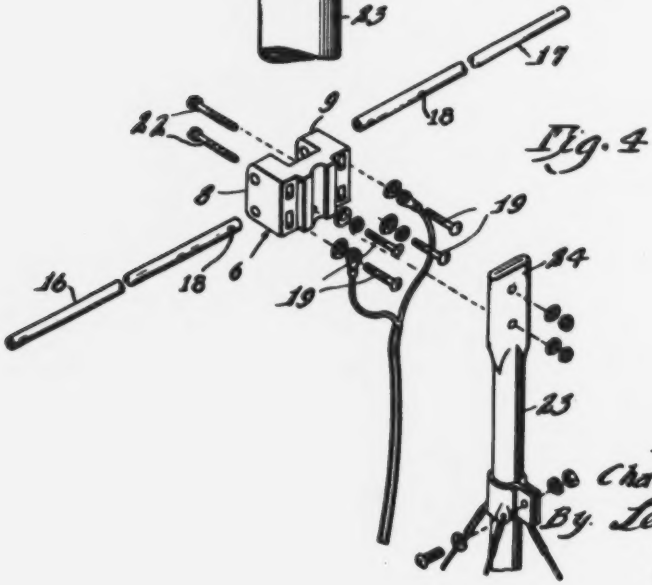



Fig. 4

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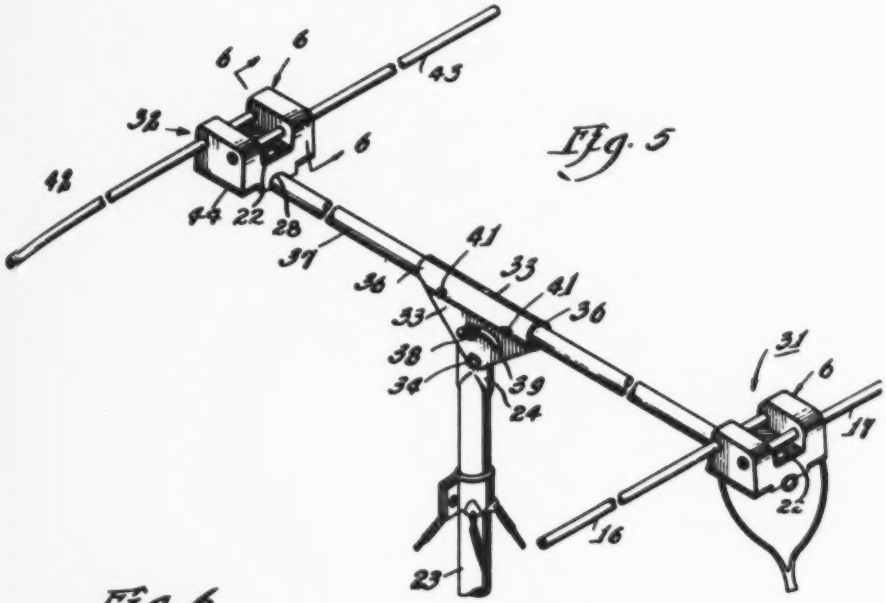
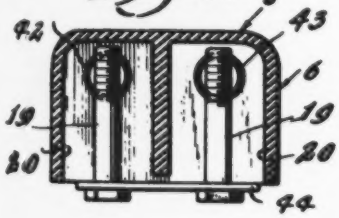



Fig. 5

Fig. 6.



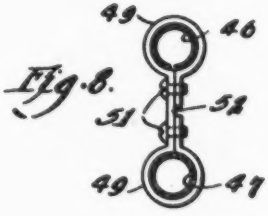
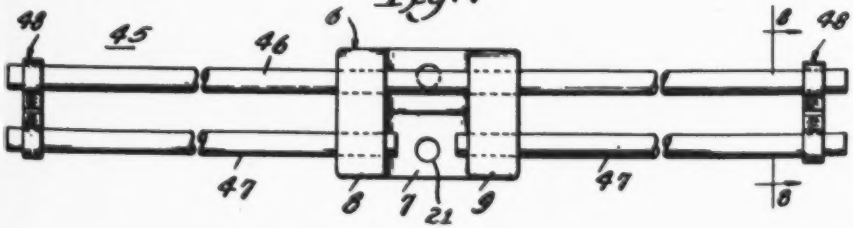




Fig. 8.

Fig. 7

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ANTENNA ARRAY

Filed Dec. 8, 1945 3 Sheets-Sheet 3

Fig. 9

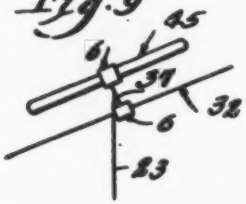



Fig. 10

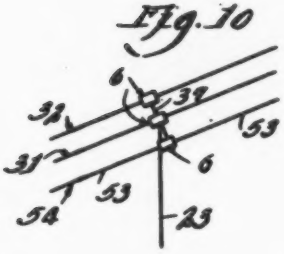



Fig. 11.

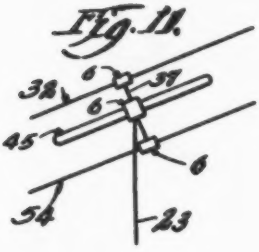



Fig. 12.

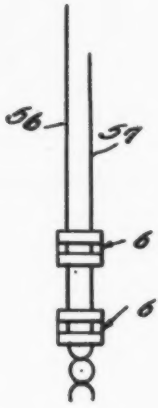
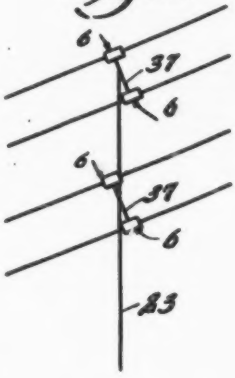



Fig. 13.



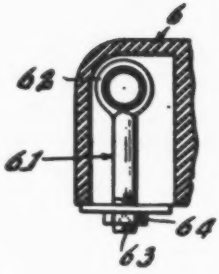




Fig. 14.

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2,481,801

# UNITED STATES PATENT OFFICE

2,481,801

## ANTENNA ARRAY

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Application December 8, 1945, Serial No. 633,732

3 Claims. (Cl. 250—33)

1

This invention relates to improvements in antenna arrays of the type now commonly employed with television, high frequency modulation, or conventional AM receiving sets, and has for an object the provision of an improved insulator mounting adapted for use in supporting antenna elements in forming various types of antenna arrays such as single dipole; folded dipole; dipole and reflector; folded dipole and reflector; dipole, reflector and director; folded dipole, reflector and director; J type antenna; and stacked arrays.

This invention further contemplates the provision of an insulator mounting which may be interchangeably used with a single or folded dipole with either vertical or horizontal polarity.

A still further object of the invention is to provide an insulator mounting of a standard type which may be used in the construction of antennas or antenna arrays, and which will lend itself broadly to the varying applications which antenna arrays may require in each specific instance.

This invention further contemplates the provision of an insulator mounting for antenna elements embodying means for detachably securing antenna elements against displacement therefrom, and other means for securing the insulator mounting to a mast or to a cross arm supported on the mast.

This invention further contemplates the provision of an insulator provided with longitudinally extending apertures preferably disposed in spaced parallel alignment to receive metallic rod-like members which may be formed and arranged to serve as dipole elements, folded dipole elements, reflectors, directors, etc.

It is a further object of this invention to reduce the cost of manufacture of the various types of antenna arrays and to facilitate assembly of the several parts in mounting an antenna array for use with a receiving set. During installation of an antenna array, it is contemplated that the antenna elements should be adjustably mounted to improve the reception of signals, and means are provided for pivotal movement of a cross member upon a supporting mast for adjustably positioning the antenna elements.

This invention embodies other novel features, details of construction, and arrangement of parts which are hereinafter set forth in the specification and claims and illustrated in the accompanying drawings wherein:

Fig. 1 is a top plan view of a single dipole array embodying the improved insulator mounting.

Fig. 2 is a front elevational view of the same.

2

Fig. 3 is a sectional view taken along the line 3—3 of Fig. 2.

Fig. 4 is an explosion view illustrating the parts embodied in the single dipole antenna array illustrated in Figs. 1 to 3.

Fig. 5 is a perspective view showing the improved insulator mounting employed in an antenna array embodying dipole and reflector elements.

Fig. 6 is a sectional view taken along the line 6—6 of Fig. 5, showing one of the shorting straps employed for electrically connecting the reflector elements.

Fig. 7 is a front elevational view showing the insulator mounting as employed in a folded dipole antenna construction.

Fig. 8 is a sectional view taken along the line 8—8 of Fig. 7.

Fig. 9 is a schematic view illustrating a folded dipole and reflector antenna array which may be constructed from parts shown in Figs. 1 through 8.

Fig. 10 is a schematic view showing an antenna array comprising a dipole, reflector and director.

Fig. 11 is a schematic view showing an antenna array comprising a folded dipole, reflector and director.

Fig. 12 is a schematic view showing a J type antenna.

Fig. 13 is a schematic view showing a stacked array.

Fig. 14 is a sectional view corresponding to Fig. 3, showing an eye-bolt for detachably connecting antenna elements to the insulator mounting.

Referring now to the drawings for a better understanding of this invention and more particularly to Figs. 1 to 3 therein, a single dipole antenna is shown as comprising an insulator 6 which may be inexpensively molded of suitable insulating material to provide a base portion 7 having a pair of end walls 8 and 9 projecting outwardly from the upper face thereof in spaced parallel relation. The end wall 8 is formed with a pair of apertures 11 and 12 disposed in spaced parallel relation, and the end wall 9 is formed with a pair of apertures 13 and 14 which are also disposed in spaced parallel relation. It will be noted that the opening 11 is in axial alignment with the opening 13 and that the opening 12 is in axial alignment with the opening 14.

The openings 11, 12, 13 and 14 provided in the end walls 8 and 9 of the insulator 6 are formed to snugly receive and engage the inner ends of dipole antenna elements 16 and 17, in the

manner illustrated in Figs. 1, 2 and 3. The dipole elements 16 and 17 may be formed of rods but are preferably formed of metallic tubing to provide maximum strength with minimum weight. The dipole elements 16 and 17 are also preferably tapered from their inner ends toward their outer ends. The inner ends of dipole elements 16 and 17 are provided with transversely extending threaded openings 18 to receive cap screws 19 disposed in openings 20 in the insulator 6 for securing the dipole elements against axial displacement from the insulator.

The insulator 6 is also provided with a pair of apertures 21 to receive bolts 22 for engaging the insulator to a mast 23. The mast is preferably formed of metallic tubing having its upper end flattened at 24 for line engagement against the flat faces 26 of a pair of spaced parallel bosses 27 formed on the back side of the insulator. The back face of the insulator is also formed with a concave arcuate surface 28 between the bosses 27 to receive a tubular supporting member, as hereinafter shown and described in connection with other forms of antenna arrays.

Figs. 5 and 6 in the drawings illustrate an antenna array embodying a dipole 31 and reflector 32. This form of antenna is shown as comprising a mast 23 having a pair of swivel plates 33 journaled on opposite sides of the flattened end 24 thereof by means of a bolt 36. The free ends of the swivel plates are formed arcuate at 36 to engage opposite sides of a transverse supporting member 37. An adjustment bolt 38 extends through an aperture provided in the mast for engagement in arcuate slots 39 provided in the swivel plates 33. By means of the bolts 38 and slots 39, the transverse supporting member 37 may be angularly adjusted with respect to the mast 23. If desired, aligning apertures may be formed to extend through the swivel plates 33 and transverse member 37 to receive bolts 41 to secure the member 37 against axial or rotational displacement with respect to the swivel plates. However, it is contemplated that the holes provided for the bolts 41 may be relocated, if desired, to angularly dispose the dipole and reflector elements between a horizontal and a vertical plane, or set screws (not shown) may be substituted in place of the bolts 41.

An insulator 6 is secured to each end of the supporting member 37 by means of bolts 22 which extend through the apertures 21 provided in the insulator and through openings provided in supporting member 37. The concave arcuate surface 28 of the insulator is formed to correspond with the contour of the supporting member 37. The dipole elements 16 and 17 are mounted on the insulator 6 by means of the screws 19 in the manner heretofore described in connection with Figs. 1 to 3 in the drawings. The reflector elements 42 and 43 are also mounted on the insulator 6 by means of screws 19 with a pair of shorting plates 44 disposed under the heads of the screws 19 for electrically connecting the inner ends of the reflector elements, as illustrated in Fig. 6.

Figs. 7 and 8 illustrate a folded dipole antenna 45 comprising an insulator 6 adapted to be supported upon a mast (not shown) similar to mast 23 to receive, for example, a half-wave length antenna element 46 and a pair of quarter-wave length antenna elements 47. The antenna element 46 is secured to the insulator 6 intermediate its ends by means of screws (not shown) similar to screws 19, and the inner ends of the antenna



elements 47 are secured on the insulator 6 in spaced parallel relation to the element 46 by means of screws (not shown) similar to screws 19. The elements 46 and 47 are connected at their ends by means of a metallic shorting clamp 48 formed with loop portions 49 to receive said elements connected by a web 52. A pair of screws 51 are provided to clamp the loop portions into tight engagement around the antenna elements.

Fig. 9 is a schematic illustration of another form of antenna array embodying a folded dipole 45 of the type illustrated in Figs. 7 and 8, and a reflector 32 of the type illustrated in Figs. 5 and 6. The insulators 6 are secured to the ends of a transverse supporting member 37 which is pivotally connected to a mast 23 by means of swivel plates 33 in the manner heretofore shown and described in connection with Fig. 5 in the drawings.

Fig. 10 is a schematic illustration of another form of antenna array embodying a dipole 31, a reflector 32, and a director 54. The dipole 31 and reflector 32 are constructed in the manner heretofore described with reference to Fig. 5 in the drawings, and the director is formed of similar parts including an insulator 6 and a pair of director elements 53. The dipole, reflector and director are supported upon a transverse member 37 which, in turn, is connected to swivel plates 33 mounted on the mast 23 in accordance with the disclosure in Fig. 5.

Fig. 11 is a schematic illustration of another form of antenna array embodying a folded dipole assembly 45, a reflector assembly 32, and a director assembly 54, said assemblies being mounted on a transverse member 37 pivotally connected to a mast 23.

Fig. 12 is a schematic illustration of a J type antenna embodying a half-wave length antenna element 56 and a quarter-wave length antenna element 57 which are mounted upon a pair of insulators 6 by means of screws (not shown) similar to screws 19.

Fig. 13 is a schematic illustration showing a stacked array of antenna elements adapted to be mounted in insulators 6 secured to the ends of transverse members 37.

In some forms of antenna arrays it may not be desirable to secure the antenna elements to the insulator 6 by means of screws 19 in the manner illustrated in Fig. 3. Fig. 14 illustrates the use of eye-bolts 61 formed with an eye portion 62 to receive an antenna element, the bolts being threaded at 63 to receive a nut 64. By threading the nut 64 along the threaded shank of the eye-bolt 61, the antenna elements are secured in tight frictional engagement against the walls of the apertures adapted to receive them as hereinbefore described in conjunction with the insulator 6.

In the construction of antenna arrays of the several types shown and described, it will be noted that the mast 23, transverse supporting members 37, and antenna elements may be formed from standard size tubing, if desired, and that the several parts may readily be assembled to provide the desired type of antenna array by means of the improved insulator 6. It will thus be seen that various types of antenna arrays are relatively simple and inexpensive to manufacture and may readily be assembled at the point of use. By providing swivel connection plates 33 between the mast 23 and the cross arms 37, the antenna elements may readily be adjusted to improve high frequency reception.

Throughout the claims, the term "antenna ele-

mast" is used as a generic term to define dipoles, reflectors, directors, etc., unless limited to a specified type of antenna element.

While this invention has been shown in several forms, it is obvious to those skilled in the art that it is not so limited but is susceptible of various changes and modifications without departing from the spirit and scope of the claimed invention.

I claim as my invention:

1. An insulator mounting for rod-like antenna elements comprising a body portion having a pair of walls extending outwardly in spaced relation from the front face thereof, each of said walls being formed with a pair of apertures to receive rod-like antenna elements, and bolt receiving apertures formed in the rear face of the body portion to intersect each of said antenna receiving apertures.

2. An insulator mounting for elongated antenna elements comprising a body portion having an obverse face and a reverse face, a pair of spaced ribs formed upon the reverse face to provide a seat upon an antenna mast, a pair of walls extending outwardly from the obverse face of the body at opposite ends of said body, each of said walls being provided with a pair of apertures to receive elongated antenna elements, said walls being provided with bolt-receiving apertures opening to the reverse face of said body and intersecting said antenna-receiving apertures whereby said antenna elements may be secured in said antenna-receiving apertures, said body being provided with bolt-receiving apertures between said ribs whereby said body may be secured in seated position upon an antenna mast.

3. An insulator mounting for elongated antenna elements comprising a body portion having



an obverse face and a reverse face, a pair of spaced ribs formed upon the reverse face providing a . ocess between said ribs co-extensive with said ribs for the reception in supporting registration of an antenna supporting member, a pair of walls extending outwardly from the obverse face of the body at opposite ends of said body, each of said walls being provided with a pair of apertures to receive elongated antenna elements, said walls being provided with bolt-receiving apertures opening to the reverse face of said body and intersecting said antenna-receiving apertures whereby said antenna elements may be secured in said antenna-receiving apertures, said body being provided with bolt-receiving apertures between said ribs whereby said body may be secured in seated position upon an antenna supporting member.

CHARLES F. VALACH.


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JFD EXHIBIT 3D.

Feb. 26, 1952 I. A. GROSS 2,587,146

ANTENNA

Filed Oct. 15, 1948

Fig. 1

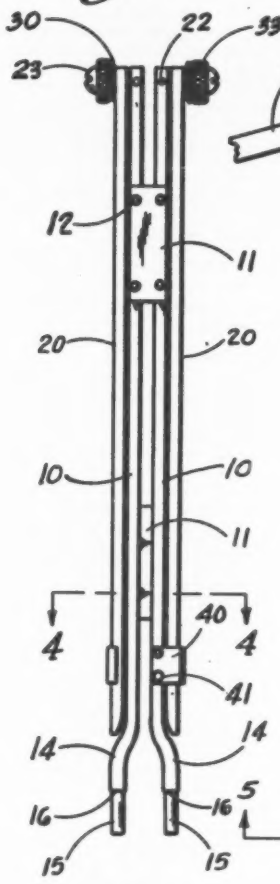


Fig. 2

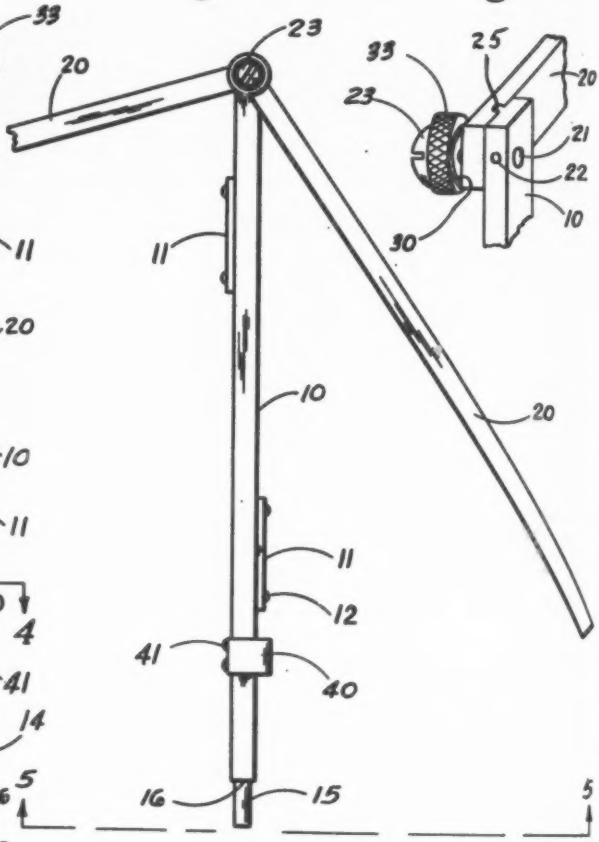


Fig. 3




Fig. 4

Fig. 5

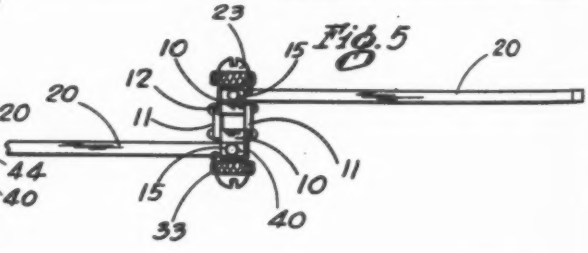


Fig. 6

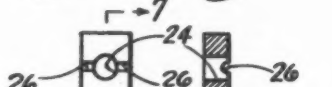


Fig. 7




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J. D. Douglas

Patented Feb. 26, 1952

2,587,146

# UNITED STATES PATENT OFFICE

2,587,146

## ANTENNA

Irving A. Gross, Cleveland, Ohio, assignor, by mesne assignments, to Stewart-Warner Corporation, Chicago, Ill., a corporation of Virginia

Application October 15, 1948, Serial No. 54,630

3 Claims. (Cl. 250—33)

1

This invention relates to improvements in antennas and more particularly relates to antennas for highly portable receivers and transmitters known as dipoles.

Heretofore, one of the main disadvantages in portable radio apparatus resided in the fact that the antennas were inconveniently located, were relatively bulky, and were not as efficient as was desired.

By the present invention, I have provided an antenna which may be quickly and easily attached or removed from the transmitter, which can be folded into a very small package, and which is highly efficient.

Briefly, the invention comprises a transmission line, which supports the antenna, and a dipole for the radiator which may be folded against the transmission line while not in use. Because of its construction, it is possible to use the transmitter in such a manner as to polarize the waves in any desired direction.

Still other advantages of the invention, and the invention itself, will become more apparent from the following description of an embodiment thereof, which description is illustrated by the accompanying drawings and forms a part of this specification.

In the drawings:

Fig. 1 is an elevational view of my antenna completely folded;

Fig. 2 is a view showing the radiator portions partly unfolded;

Fig. 3 is an enlarged section of one of the joints between the radiator and the transmission line showing the manner in which it may be locked into position.

Fig. 4 is a section on the line 4—4 of Fig. 1;

Fig. 5 is a fragmentary bottom plan view of the antenna in unfolded position;

Fig. 6 is a fragmentary end view of the radiator;

Fig. 7 is a view on the line 7—7 of Fig. 6.

Referring to the drawings, throughout which like parts are designated by like reference characters, my antenna comprises a transmission line of rigid construction, to the ends of which are hingedly connected the radiator portions to provide a dipole. The dipole section may be folded up against the transmission line to form a compact package but little larger than a pencil.

As best shown in Fig. 1, the transmission line comprises two spaced parallel rectangular cross section metal bars or rods 10, held in spaced parallel relation to each other by blocks of insulation material 11. The blocks are held to the rods

2

10 by screws or rivets 12 which extend through the blocks into the rods. Preferably, the blocks are spaced apart longitudinally and are placed on opposite sides of the rods. It will be appreciated that the blocks could be placed between the rods or that in some instances the rods could be molded in a solid piece of dielectric material.

The spacing of the rods is such that in any instance the surge impedance of the line is 100 ohms. This also could be varied as is well known to those versed in the art, since in some instances it may be desirable to have 72 ohms or even 300 ohms impedance in the line. The only thing to be observed is that the lines be held in fixed relation to each other and to maintain a fixed impedance and that they be rigid.

At the lower end of the line, the rods are bent outward in an S curve as indicated at 14 and are provided at their extremities with prongs 15 having a shoulder 16. They serve as a plug-in connection for the transmitter, receiver or transceiver with which the antenna is to be used.

At the upper end of the transmission line the radiators 20 are hingedly secured. These radiators are so secured to the end of the line that they may be unfolded out in opposite directions, normal to the transmission line.

As best shown in Fig. 3, the end of the bar 10 has a pivot pin 21 disposed thereon and held in place by a lock pin 22. For convenience in assembly, this pin 21 is shown as a screw, the head 23 of which extends from the side of the bar spaced therefrom.

The radiator 20, as best shown in Fig. 6, is provided with an aperture 24 to allow it to be journaled on the pin or screw 21. This end of the radiator is also provided with a groove 26 crossing the pivot point, adapted to receive a rib 25 on the transmission line 10 when the radiator is in extended position.

A spring washer 30 is provided, which washer is interposed between an adjusting nut 33 and the end of the radiator.

The nut 33 allows the tension on the washer to be adjusted to provide the desired ease of operation, while the head 23 on the pin prevents the loss of the parts.

Each of the transmission line bars 10 is provided with a spring clip 40 of L-shaped formation (Fig. 4) secured to the bar by screws or rivets 41. Each clip is secured to the edge of a bar and then extends parallel to the side of the bar. Each extends in opposite direction as shown in Fig. 4, and the free end of each is provided with a beaded edge 44. These clips engage with the

radiators when they are folded down alongside the transmission bars to hold the same in folded position.

In operation, the device is stored in a folded state, as shown in Fig. 1 where it is to be used. It may be plugged into the receiver and the radiators released from engagement with the clips 46 and unfolded as shown in Fig. 2. When the radiators are extended normal to the line bars, they snap into position due to the spring washer 38 engaging in the grooves and are held in this position.

The spring washer construction is a distinct advantage because it provides a firm contact of the parts with each other, which parts may be brass, or silver plate; and further, because although the radiators are held in a fixed position with sufficient tension to prevent them from folding, if the antenna should strike an obstruction, the parts will fold up rather than bend.

It will thus be apparent that I have provided an antenna supported solely by a transmission line and which is foldable. It will also be apparent that because of the stiffness of the parts, there is less aptitude for changes in transmission characteristics due to bending when the device is moved, and that the transceiver with its antenna may be held with the directors vertical, horizontal or oblique to provide the desired polarization of the waves.

Having thus described my invention, I am aware that numerous and extensive departures may be made therefor without departing from the spirit or scope of my invention.

I claim:

1. An antenna comprising a pair of rods, means for holding said rods in spaced parallel relation to each other to form a transmission line of determined impedance, each of said transmission lines having hingedly secured thereto a radiator section, said radiator sections forming a dipole radiator, and spring means for locking said radiator sections in predetermined positions.

2. An antenna comprising a pair of stiff bars held in predetermined spaced relation by insulation means to form a transmission line of predetermined impedance, said bars being provided with plug-in terminals at one end, a pin secured in each bar at the other end and a radiator section hingedly disposed on each pin, spring means for locking said radiator section in predetermined position and means to adjust the tension of said spring means.



3. An antenna comprising a pair of stiff bars held in predetermined spaced relation by insulation means to form a transmission line of predetermined impedance, said bars being provided with plug in terminals at one end, a pin secured in each bar at the other end and a radiator section hingedly disposed on each pin, spring means for locking said radiator section in predetermined position and means to adjust the tension of said spring means, said transmission bars being provided with spring clips, said spring clips being disposed to receive and hold said radiator sections when folded.

IRVING A. GROSS.


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Sept. 19, 1961 J. R. WINEGARD 3,001,195

ANTENNA STRUCTURE

Filed April 20, 1960 2 Sheets-Sheet 1

Fig. 1.

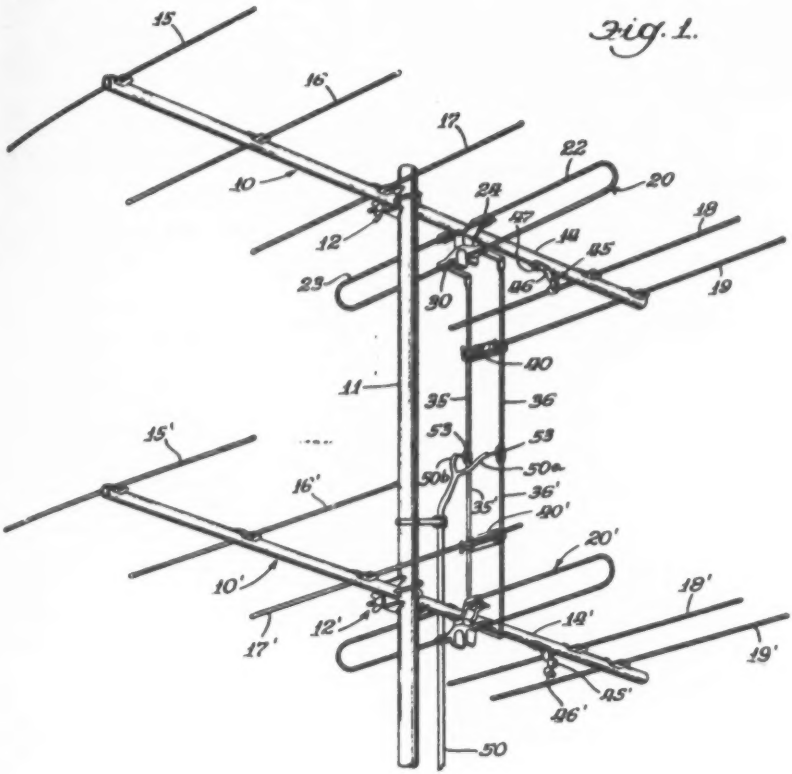
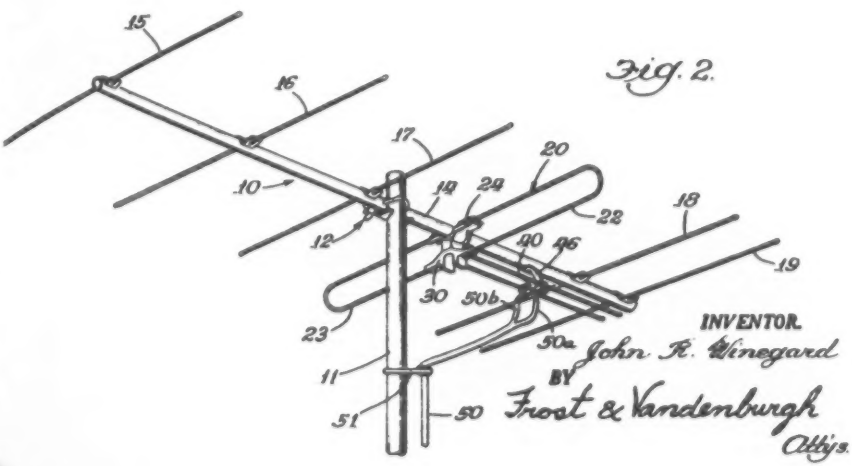



Fig. 2.

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Sept. 19, 1961 J. R. WINEGARD 3,001,195

ANTENNA STRUCTURE

Filed April 20, 1960 2 Sheets-Sheet 2

Fig. 3.

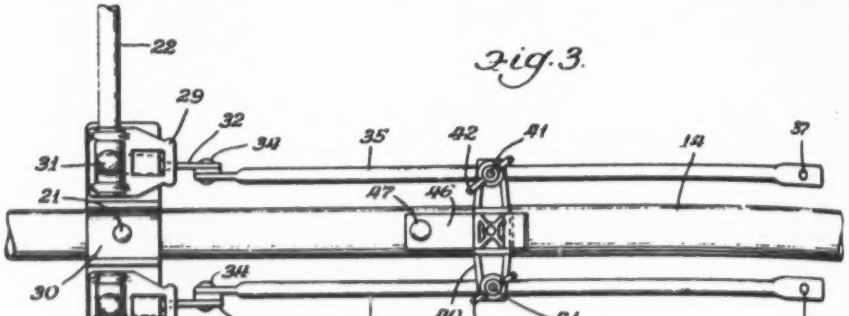



Fig. 4.

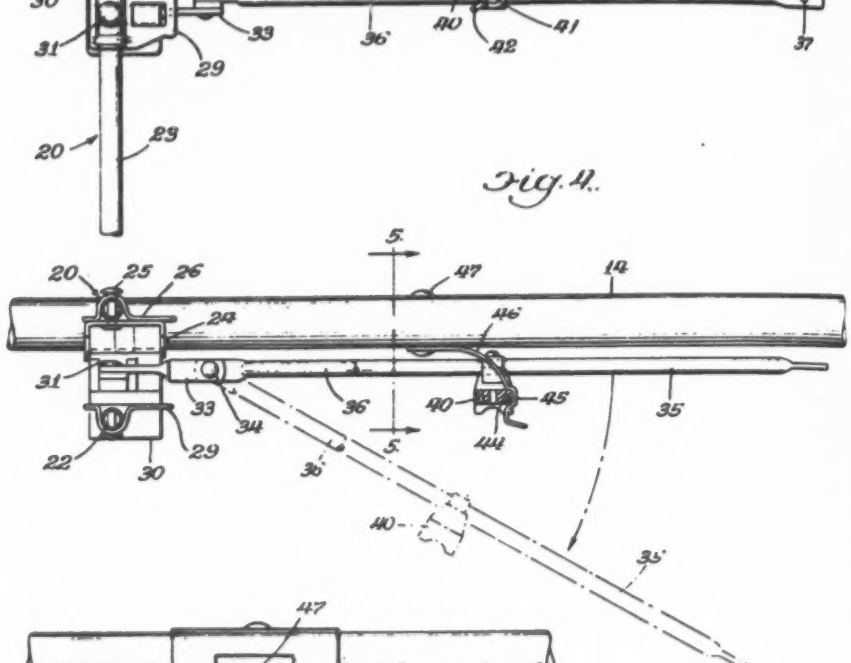
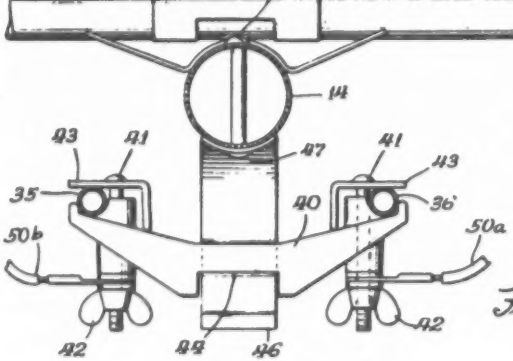



Fig. 5.




INVENTOR.
John R. Winegard
BY
Frost & Vandenburgh
Attys

United States Patent Office 3,001,195 Patented Sept. 19, 1961



3,001,195

# ANTENNA STRUCTURE

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Filed Apr. 20, 1960, Ser. No. 23,488
7 Claims. (Cl. 343—864)

The present invention relates to an antenna structure having matching stubs which not only enable the obtaining of an impedance match between the antenna and the lead-in but also facilitate the installation of the antenna.

With antennas which are to be used for high frequency, very high frequency and ultra high frequency radio waves, such as for example those utilized in frequency modulation and television transmission, it is particularly important that the impedance of the transmission line match the impedance of the antenna. For most installations of television antennas a 300 ohm transmission line is employed. Such a transmission line is relatively inexpensive and is easy to install between the antenna and the receiver.

Where the only element, or the driven element, is a dipole, it is not particularly difficult to obtain a reasonably accurate match in impedances between the 300 ohm line and the dipole. Folded dipoles, which are more commonly used, in theory have an impedance of slightly less than 300 ohms and actually are somewhat below this in the usual instance. In high signal strength areas the impedance mismatch normally is not too troublesome. However, in fringe areas the matter of a proper match between the folded dipole and the antenna lead-in becomes more significant. Furthermore, in antennas for fringe areas it is common to use a plurality of parasitic elements on the antenna in addition to the driven element to improve the strength of the signal from the antenna and the directivity of the antenna. The use of these parasitic elements substantially lowers the antenna impedance. The extent to which it is lowered will depend upon the number and positioning of the parasitic elements with respect to the driven element. With many antennas designed for fringe area operation the impedance will be well below 300 ohms. Thus there is a problem of obtaining a proper match between the antenna and the transmission line. Various systems have been devised for obtaining a match including the use of open quarter wave matching stubs.

For fringe area reception it is quite common to use a series of stacked antennas. Thus two or more antennas are positioned one above the other on a single mast and connected together to feed the transmission line. When this practice is followed the impedance matching problems again are encountered. Generally speaking it is desirable to connect the electrical transmission line midway between the two or more antennas and in such case the total impedance of the antenna system as seen by the transmission line is a fraction of the impedance of any one antenna. For example, with two antennas in the system with the transmission line being connected midway between the two antennas the impedance of the antenna system as seen at the point of connection of the transmission line is one-half of the impedance of each individual antenna.

The principal object of my invention is to provide an antenna structure which incorporates impedance matching elements to provide a suitable 300 ohm impedance connection for attaching a 300 ohm line to a single antenna and which can be used in stacking two similar antennas to provide a 300 ohm connection for the transmission line midway between the two stacked antennas. One advantage of the structure I have devised is that while a connection is provided at 300 ohms to match the commonly used 300 ohm transmission lines to a single antenna this connection may be varied to give an impedance as seen at the transmission line connection of anything between the actual impedace of the driven element, say 100 to 150 ohms, up to 600 ohms. Thus, in those special instances where it is desired to use such an antenna with for example a 450 or 600 ohm transmission line the antenna connections may be quickly adjusted to provide an impedance of the desired value as seen at the transmission line connections.



Further objects and advantages of my invention include: the impedance matching structure is easy and simple to construct and inexpensive to add to any one of the various types of commonly used receiving antennas; the structure may be used with any one of the numerable variations that exist in receiving antennas, e.g. variations in number and positioning of parasitic elements, etc., and still provide a proper 300 ohm match for the connection of the transmission line; the device not only provides a 300 ohm connection for a pair of stacked antennas but also acts as a stacking harness and facilitates the installation of a pair of stacked antennas.

Additional objects and advantages will become apparent from the following decription taken in conjunction with the drawings in which:

FIGURE 1 is a perspective view of a pair of antennas embodying my invention stacked and harnessed together to feed a single transmission line;

FIGURE 2 illustrates one of the antennas of FIGURE 1 used alone on a mast to feed the transmission line;

FIGURE 3 is an enlarged bottom view of the impedance matching structure;

FIGURE 4 is a partial elevational view partially in section, showing the structure of FIGURE 3; and

FIGURE 5 is an enlarged section as seen at 5—5 of FIGURE 4.

Referring to FIGURE 2 there is illustrated an antenna generally **10** affixed to a mast **11** by a clamp generally **12**. FIGURE 1 illustrates two identical antennas **10** and **10'** secured to a mast **11** by clamps **12** and **12'** respectively.

Each of the antennas **10** includes a metal boom **14** on which are five metal parasitic elements and a driven element. The five parasitic elements are directors **15**, **16** and **17** and the reflectors are **18** and **19**. The driven element in the illustrated embodiment is a folded dipole generally **20**. In the illustrated embodiment each of the elements **15–20** is made so that it may be folded generally parallel to boom **14** to facilitate packing and shipping of the antenna. However, this feature is not a significant part of the present invention. As is the conventional practice, boom **14** and parasitic elements **15–19** are all conductors and are electrically connected together.

The structure and mounting of the dipole **20** is best seen in FIGURES 2–4. It includes a pair of elongated, generally U-shaped, members **22** and **23** which are attached to a metal saddle **24** by rivets **25**. A rivet **21** is used to attach saddle **24** and an insulator **30** to boom **14**. A pair of straps **26** are received over the upper ends of members **22** and **23**. Rivets **25** secure the top ends of members **22** and **23** between straps **26** and saddle **24**. Saddle **24** and rivets **21** and **25** form an electrical connection between the top ends of members **22** and **23** and boom **14**.

Below and attached to saddle **24** is an insulator **30**. The lower ends of members **22** and **23** are spaced along the length of insulator **30** and secured to the insulator by bottom straps **29** and rivets **31**. Attached to the upper ends of rivets **31** are a pair of generally horizontal posts **32** and **33**. Posts **33** are positioned in a generally horizontal plane slightly below boom **14**. Post **32** lies generally in a plane parallel to and at one side of mast **14**. Similarly, post **33** lies in a plane generally parallel to and

at the opposite side of boom 14. Rivets 34 pass through posts 32 and 33 adjacent the outstanding ends thereof. Bars 35 and 36 are attached to posts 32 and 33 respectively by rivets 34. Each of bars 35 and 36 are made from tubing flattened at the ends. The extending ends are provided with openings 37 through which connecting bolts are inserted when two of the antenna units are stacked as hereinafter described.

Intermediate the ends of bars 35 and 36 is in insulator 40 which extends between the bars. Bolts 41 pass through bosses at the opposite ends of insulator 40 and are held in place by wing nuts 42. L shaped members 43 under the heads of bolts 41 clamp the members 35 and 36 against insulator 40 and provide an electrical connection from the bars 35 and 36 to bolts 41. Intermediate the ends of insulator 40 is a recess 44 (best seen in FIGURES 4 and 5 to receive the U shaped portion 45 of a spring clip 46. Clip 46 is attached to boom 14 by a rivet 47.

The posts 32 and 33 and the bars 35 and 36 connected thereto are essentially a linear one-quarter wave matching transformer. The principles of such transformers are well known in the art and from the available knowledge one skilled in the art can readily develop the particular size and spacing of components for a specific antenna. See for example pages 103–107 and 165–168 of The A.R.R.L. Antenna Book of the American Radio Relay League, Inc. (1954), the disclosure of which book is incorporated herein by reference. My invention resides in the structure of such a transformer which not only facilitates the installation and the obtaining of the proper impedance match with a single antenna, but also does the same thing when two such antennas are to be stacked.

Since, in by far the majority of cases the antennas sold will be for installations where a 300 ohm dual lead-in is used, the insulator 40 will be clamped into place on bars 35 and 36 in a position such that L members 43 contact the bars at a point such that when the clip is engaged with insulator 40 as illustrated in FIGURES 3–5 the insulator will be in the proper position along bars 35 and 36 to provide the desired 300 ohm connection.

When the user or installer receives the antenna it will of course first be unpacked. Usually, to facilitate the packing, elements 15–20 are folded generally parallel to boom 14 so that the first step will be to unfold the elements. The boom 14 then will be secured to mast 11 by clamp 12 and the dual wire lead-in 50 will be connected to the bolts 41 by wing nuts 42. One of the wires 50*a* will be connected to one of the bolts 41 and the other wire 50*b* will be connected to the other bolt 41. The lead in 50 then will be run to the receiver and may be supported by suitable stand-off insulators 51. The exact sequence of the steps of erecting mast 11, connecting lead-in 50 and fastening boom 14 to mast 11 will depend upon the preferences of the particular installer. In any event it is an extremely simple operation for the installer to erect the antenna 10 and to connect the lead-in 50 thereto in a manner such that a proper match is obtained between the 300 ohm lead-in 50 and the impedance of antenna 10.

In an extremely few instances an individual may wish to use a lead-in having an impedance different than 300 ohms, say for example 450 ohms. In that instance the wing nuts 42 are loosened and the insulator 40 disengaged from spring clip 46. The insulator is then moved longitudinally of bars 35 and 36 until L members 43 contact the bars at a point such that the desired impedance will appear at the terminals provided by bolts 41. If for example 450 ohms is the desired impedance, insulator 40 will be moved toward the ends (as represented by openings 37) of bars 35 and 36. The impedance at the open end of the bars will be approximately 600 ohms. When the desired position of insulator 40 is determined, the insulator is clamped in place by bolts 41 and a suitable support provided between boom 14 and insulator 40. A support may be fabricated by a number of turns of electrician's tape between the insulator and the boom.



If two stacked antennas are to be installed, as illustrated in FIGURE 1, the top antenna 10 is secured to mast 11 and insulator 40 is disengaged from clip 46 to permit the insulator and bars to swing downwardly about rivets 34 as illustrated in dotted lines in FIGURE 4. On the bottom antenna both of wing nuts 42' are loosened and one of them is removed so that the insulator may be swung about the other of the bars 35' or 36'. The insulator 40' is then disengaged from the clip 46; the insulator swung about the bar to which it is loosely connected so as to clear boom 14'; and both of bars 35' and 36' are swung upwardly over boom 14'. The insulator 40' is then reconnected to both of the bars and wing nuts 42' tightened in place on bolts 41'. Antenna 10' is then fastened on mast 11, aligned directly under antenna 10 with the openings 37 in bars 35 and 36 aligned vertically with the openings 37' in bars 35' and 36'. Bolts 53 are then inserted through openings 37 and 37' in each pair of bars to connect the respective pairs of bars to each other and to the wires 50*a* and 50*b* of lead-in 50. Since the impedance seen at the ends of bars 35 and 36 which ends are represented by openings 37 is 600 ohms the combined impedance when two antennas are connected as illustrated in FIGURE 1 will be 300 ohms as seen by the lead-in 50 connected to bolts 53.

The antenna construction herein described is suitable for antennas intended for reception of one TV channel, several closely spaced channels, and for all channel antennas. The antenna of FIGURES 1 and 2, for example, is especially suitable for reception of TV channel 13. In an actual construction, the following approximate dimensions were used:

| | |
|---|---|
| Arms 33–33 | ¼" dia., spaced 2¼", 15" overall length. |
| Length of arm 33 | 2" (center of element 20 to rivet 34); |
| Length of arm 35 | 12¼" (rivet 34 to hole 37). |
| Dipole 20 | Each arm 26½" (before folding) with rivets 21 spaced 3". |
| Director 17 | 24" long, 10" in front of element 18. |
| Director 16 | 23½" long, 20¼" in front of element 20. |
| Director 15 | 23⅛" long, 32¾" in front of element 20. |
| Reflector 18 | 27⅝" long, 14¾" behind element 20. |
| Reflector 19 | 27⅝" long, 19¼" behind element 20. |
| Boom 14 | 1" diameter. |

The dipole, directors, and reflectors were of ⅜" outside diameter tubing. All conductors and the boom were of aluminum.

The above dimensions illustrate a particular antenna construction and may be varied without substantially altering the antenna performance. Also, if it is desired to receive some other channel or channels, the dimensions used are appropriately varied.

The foregoing description of a specific embodiment is for the purpose of complying with 35 USC 112 and should not be construed as imposing unnecessary limitations upon the appended claims inasmuch as modifications and variations thereof will be apparent of those skilled in the art, and such modifications and variations are deemed to be within the scope of my invention to the extent that they are not excluded by the limitations of the claims.

I claim:

1. In an antenna including a mast member, a boom member, a driven element and a parasitic element, the improvement comprising: a pair of fixed, spaced, connector posts attached to said boom and electrically connected to said driven element; a pair of elongated relatively rigid bars, each bar being secured to a post respectively for pivotal movement about a generally horizontal axis; and insulator means connected to each of said bars to releasably support said bars from one of said members.

2. In an antenna including a mast member, a boom

member, a driven element and a parasitic element, the improvement comprising: a pair of fixed, spaced, connector posts attached to said boom and electrically connected to said driven element; a pair of elongated relatively rigid bars, each bar being secured to a post respectively for pivotal movement about a generally horizontal axis; an insulator interconnecting said bars and positioning said bars in a generally parallel relationship; and means to support said bars from one of said members.

3. In an antenna including a mast member, a boom member, a driven element and a parasitic element, the improvement comprising: a pair of fixed, spaced, connector posts attached to said boom and electrically connected to said driven element; a pair of elongated relatively rigid bars, each bar being secured to a post respectively for pivotal movement about a generally horizontal axis; an insulator extending between said bars; means releasably connecting said insulator to said bars and positioning said bars generally parallel to each other; and a clip releasably affixing said insulator to one of said members.

4. In an antenna including a boom member, a driven element and a parasitic element, which may be mounted singly on a mast member or stacked on the mast member with a like antenna, the improvement comprising: a pair of fixed, spaced, connector posts attached to said boom and electrically connected to said driven element; a pair of elongated relatively rigid bars, each bar being secured to a post respectively for pivotal movement about a generally horizontal axis at one end of the bar, the length of said bars from said axis to the other ends of bars being approximately one-half of the stacking distance; and insulator means connected to each of said bars intermediate the ends thereof to releasably support said bars from one of said members.

5. In an antenna including a horizontal boom, a driven element and a parasitic element, which may be mounted singly on a mast or stacked on the mast with a like antenna and connected by a pair of lead wires to radio wave equipment, the improvement comprising: a pair of fixed, spaced, connector posts extending parallel to said boom and to either side of said boom, said posts having extending ends in a plane normal to said boom with the plane being spaced from said driven element, said posts being electrically connected to said driven element; a pair of elongated relatively rigid bars, one end of each of said bars being secured to an extending end of a post respectively for pivotal movement about an axis parallel to said plane; an insulator extending between said bars intermediate the ends thereof; means releasably connecting said insulator to said bars and positioning said bars in planes generally parallel to said boom, said means providing connectors for said lead wires when said antenna is used singly; and means at the other ends of said bars for connecting the bars of one antenna with the respective bars of a second antenna when the antennas are to be stacked on a mast.



6. In an antenna including a horizontal boom, a driven element and a parasitic element, which may be mounted singly on a mast or stacked on the mast with a like antenna and connected by a pair of lead wires to radio wave equipment, the improvement comprising: a pair of fixed, spaced, connector posts extending parallel to said boom and to either side of said boom, said posts having extending ends in a plane normal to said boom with the plane being spaced from said driven element, said posts being electrically connected to said driven element; a pair of elongated relatively rigid bars, one end of each of said bars being secured to an extending end of a post respectively for pivotal movement about an axis parallel to said plane; an insulator extending between said bars intermediate the ends thereof; means releasably connecting said insulator to said bars and positioning said bars generally parallel to said boom, said means providing connectors for said lead wires when said antenna is used singly; clip means to releasably engage said insulator and said boom, said clip means positioning bars in a generally horizontal plane when engaged; and means at the other ends of said bars for connecting the bars of one antenna with the respective bars of a second antenna when the antennas are to be stacked on a mast.

7. An antenna for connection to a twin transmission line, said antenna comprising a generally horizontal boom having a longitudinal axis, an insulator affixed to said boom with at least a portion of the insulator being spaced vertically with respect to said boom; a driven element having two feed ends, said element extending outwardly at opposite sides of said axis with said ends being attached to said insulator at opposite sides of the axis; a pair of generally horizontal posts affixed to said insulator at opposite sides of said axis respectively and electrically connected to said ends respectively, said post extending in one direction generally parallel to said axis and having extending ends beyond the adjacent portions of the element in said direction; a first elongated bar having one end pivotally attached to one post adjacent the extending end thereof; a second elongated bar having one end pivotally attached to the other post adjacent the extending end thereof; a second insulator extending between said bars and maintaining said bars substantially parallel; said posts and said bars forming a quarter wave matching transformer; means to releasably engage said second insulator and said boom; and means to connect said transmission line to said bars at a plurality of points along the length of the bars respectively.

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JFD EXHIBIT 3F.

May 30, 1950 J. D. CALLAGHAN 2,510,010

HIGH-FREQUENCY ANTENNA SYSTEM

Filed June 5, 1948 2 Sheets-Sheet 1

Fig. 1

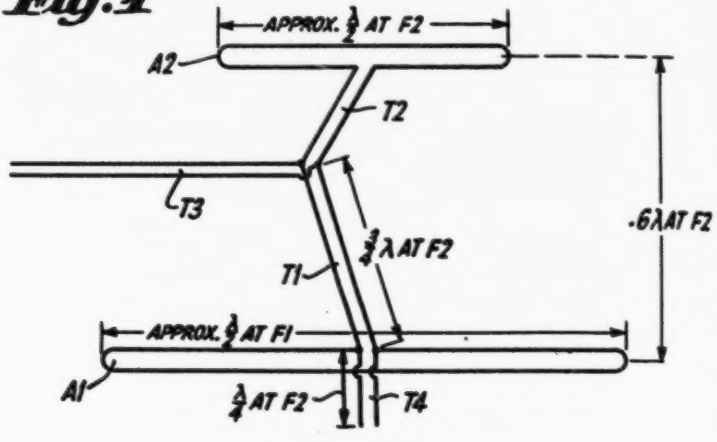
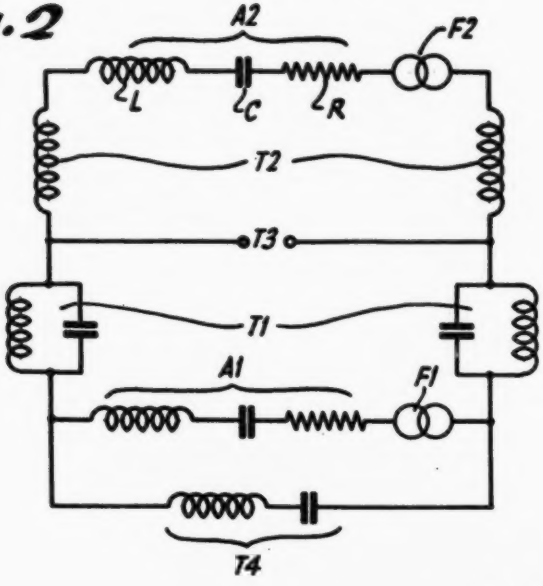



Fig. 2

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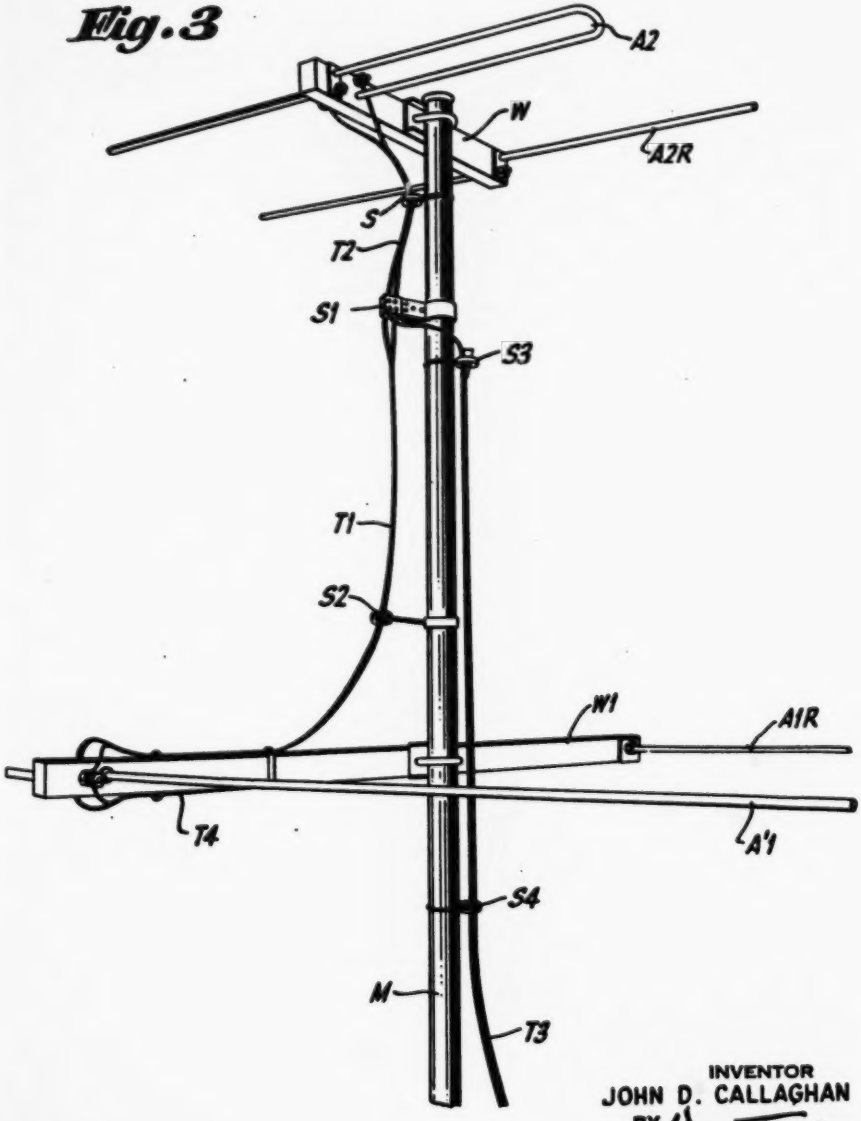
May 30, 1950 J. D. CALLAGHAN 2,510,010

HIGH-FREQUENCY ANTENNA SYSTEM

Filed June 5, 1948 2 Sheets-Sheet 2

Fig. 3




INVENTOR
JOHN D. CALLAGHAN
BY Harry Tonick
ATTORNEY

Patented May 30, 1950 2,510,010

# UNITED STATES PATENT OFFICE

2,510,010

## HIGH-FREQUENCY ANTENNA SYSTEM

John D. Callaghan, Merchantville, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application June 5, 1943, Serial No. 21,302

9 Claims. (Cl. 250—33.65)

1

This invention relates generally to high frequency broad band receiving antenna systems, and particularly to an arrangement for simultaneously feeding energy from a plurality of antennas resonant to different frequencies into the same transmission line. It is particularly applicable to television receiving systems.

One of the objects of the invention is to enable a plurality of receiving antennas of different dimensions which are adapted to receive waves of different frequencies to feed the same transmission line (extending to a receiver) over different branch circuits in such manner that each branch and associated antenna has negligible effect on the flow of high frequency energy from the other branch toward the common transmission line.

Another object is to enable two high frequency directive receiving antennas of different dimensions which are oriented in different directions to be coupled into a common transmission line in such manner as to prevent the flow of energy of any one antenna circuit into the other antenna circuit, while preserving the directivity pattern of each antenna and maintaining maximum efficiency in the collection of energy and the transmission thereof from each antenna to the common transmission line.

To achieve the results of the invention, use is made of a circuit arrangement which enables the unrestricted flow of energy from each branch circuit and its associated receiving antenna toward the common transmission line extending to the receiver, while making each branch appear at the junction to the common transmission line as a circuit of extremely high impedance to the flow of energy from the other branch circuit. A section of line of predetermined length is placed across the antenna of larger dimension at a particular location in order to provide a short circuit for any signals of a frequency adapted to be collected on the shorter antenna. The arrangement is such that at a particular frequency relationship of two-to-one any tendency toward second harmonic operation of the larger antenna is suppressed, thus preventing interference from energy collected by the larger antenna at its second harmonic mode of operation with the directivity pattern of the smaller antenna.

A more detailed description of the invention follows in conjunction with a drawing wherein,

Fig. 1 illustrates diagrammatically an antenna system in accordance with the invention in which two receiving antennas of different dimensions feed a common transmission line over individual branch circuits;

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Fig. 2 illustrates the equivalent electrical circuit of Fig. 1; and

Fig. 3 illustrates a perspective view of a preferred form of mechanical construction of the antenna arrangement of the invention, and shows suitable supporting arms and mountings for the antenna elements.

Referring to Fig. 1 in more detail, there is shown a pair of receiving antennas of different dimensions A1 and A2 coupled through separate branch circuits T1 and T2 to a common transmission line T3, in turn, extending to a receiver such as a television receiver. Antenna A1 has a larger dimension than A2 and is adapted to receive signals of frequency F1 which is lower than the frequency of the signals F2 adapted to be received on antenna A2. By way of example only, let it be assumed that antenna A2 is tuned to a frequency which is twice the frequency of the signals adapted to be received on antenna A1. Both antennas A1 and A2 are shown to be of the folded dipole type although, if desired, either or both of these antennas may be of the single dipole type fed at the center. The length of antenna A2 from one end to the other is made to be approximately a one-half wavelength at it frequency of operation F2. The length of antenna A1 from one end to the other is made to be approximately a one-half wavelength at its frequency of operation F1. It will be noted, from what has been stated above, that a signal of frequency F2 is higher than a signal of frequency F1.

It should be noted that there is provided across antenna A1 at the junction point of this antenna with the branch line T1, a section of line T4 which is open at its end removed from the antenna. Line section T4 has a length of one-quarter of a wavelength at the higher frequency F2. Branch line T1 has a length which is three-quarters of a wavelength at the higher frequency F2. Thus, the length T1 plus the length of T4 equals a length of line which is one whole wavelength at the frequency F2. In referring to these lengths, it should be understood that reference is made to the electrical lengths of these line sections and antennas rather than to the actual physical lengths.

The branch line T2 has a length which is so chosen that in combination with the antenna A2, this combination appears as an open circuit across the common transmission line T3 at the junction point at the frequency F1. Stated otherwise, the combination of transmission line T2 with antenna A2 is equivalent to a quarter wavelength of line with the far end (the end removed from the

common line T3) short circuited at the frequency F1. Thus, any energy collected by the antenna A1 and flowing over branch line T1 toward the line T3 will be presented with a high impedance circuit by combination T2, A2 and will not flow into this circuit T2, A2. The combination of antenna A1 and transmission line sections T1 and T4 present a high impedance circuit at the junction with the common line T3 for energy at the frequency F2. Thus, any signal of frequency F1 collected on antenna A2 cannot flow into transmission line T1 and can only flow into the common line T3. The line section T4 which is electrically a quarter wavelength long at frequency F2 acts, in effect, as a short circuit for signals of frequency F2. The open end of line section T4 is, in effect, inverted and becomes a short circuit at the junction point with line T1 for this same frequency F2. For the lower frequency F1, the line section T4 acts as a capacity across the antenna A1 and its magnitude is sufficiently small in relation to the frequency F1 so as to be of negligible effect on signals of this frequency F1.

The distance or physical spacing between the antennas A1 and A2 is approximately .5 wavelength at frequency F2 for optimum results.

If the antennas A1 and A2 are so dimensioned that they are adapted to receive frequencies F1 and F2 respectively, whose relationship is three-to-one, then branch line T1 which is three-quarters of a wavelength long at F2 also becomes a quarter of a wavelength long at F1. In this condition, the combination A2, T2 can be adjusted to present a slightly capacitive reactance across the junction point with common line T3 so that its capacitive reactance will cancel out the previously mentioned capacitive reactance caused by action of transmission line T4. This will come about due to the inverting action of transmission line section T1 when it is a quarter wavelength long at frequency F1.

The equivalent electrical circuit of Fig. 1 is illustrated in Fig. 2 wherein each of the antennas A1 and A2 are represented by a series circuit of inductance L, capacitance C and resistance R. The source of incoming waves of frequency F2 is shown as a generator in series with antenna A2, while the source of incoming waves of frequency F1 is shown as a generator in series with the antenna A1. The line section T2 connecting the antenna A2 to the common transmission line T3 is represented by two inductance coils, one for each leg of the line T2. These legs of line T2 are shown in series with the antenna A2 and connected between antenna A2 and terminals T3 representing the common transmission line. The quarter wavelength stub line section T4 is represented by a series circuit of an inductor and a capacitor in shunt across the antenna A1 and source F1. The line T1 which is three-quarters of a wavelength long at the higher frequency F2 is represented by two parallel tuned circuits, each parallel tuned circuit representing a leg of the line or branch T1. It should be noted that the common line T3 adapted to be connected to the receiver is connected in common to both branches of the system.

Although the line sections T1, T2, T3, T4 are indicated in Fig. 1 as being of the two-wire type, it should be understood that if desired, each of these line sections may be in the form of a coaxial line. Either air or some other suitable dielectric may be employed between the conductors of the line section.



A practical embodiment of the invention actually tried out in practice is shown in Fig. 3. The smaller dimensioned antenna A2 is shown in association with a reflector A2R positioned parallel to the antenna A2 and suitably spaced therefrom in the same horizontal plane in order to improve the directivity characteristic in a direction away from the reflector and toward the folded dipole. The reflector A2R and the antenna A2 are mounted on a wooden cross arm W which, in turn, is mounted on a vertical metallic mast M. In the embodiment actually tried out in practice, this mast M was an aluminum tube. Positioned below is the antenna A'1 shown as a single dipole. Insofar as the principles of the present invention are concerned, it is of no consequence whether the antennas are single dipoles or folded dipoles. The larger dimensioned antenna in Fig. 3 has been given a prime designation because it is shown as a single dipole but it has the same reference character except for the prime designation as the larger dimensioned antenna A1 of Fig. 1. A reflector A1R is shown parallel to antenna A'1 and in the same horizontal plane and suitably spaced therefrom. A wooden cross arm W1 is used to mount the antenna A'1 and its associated reflector A1R on the metallic mast M. The common transmission line T3 extending to the receiver is shown as a double wire line which is connected to the antenna A2 by means of branch line T2 and connected to the antenna A'1 by means of the branch line T1. The quarter wavelength stub line section T4 is shown as a pair of wires connected across the terminals of the larger antenna A'1 and tacked or suitably attached to the bottom of the wooden cross arm W1. Suitable stand-off insulators S1, S2 and S3 and S4 maintain the transmission line sections taut and in suitable position relative to the mast M. In practice, these stand-off insulators may each be in the form of a metallic clamp having a rubber grommet or ring through which the line sections pass. It is desirable from a standpoint of mechanical strength and appearance to mount the small higher frequency antenna A2 at the top of the mast and the larger small frequency antenna A1 or A'1 lower down on the mast. However, if reflections or other conditions make it necessary to mount the small antenna below the large one, the system will work equally well. Where this antenna is to be used for television purposes for which it is primarily designed, the connecting line sections, stubs, etc., should be kept tight at all times to prevent their moving in the wind; otherwise, picture "flutter" may be observed on the screen of the cathode ray tube of the television set on windy days.

The line sections T1, T2, T3 and T4 of Fig. 3 were common 300 ohm impedance transmission lines made up of parallel copper wires molded in and spaced apart by a suitable dielectric such as poly-ethylene insulation. The two cross arms W and W1 were separated vertically in the embodiment successively tried out in practice by a spacing of thirty-three inches along the mast, center to center. The high frequency antenna A2 was attached to the common junction of line T3 by a twelve-inch length of line T2. The low frequency antenna A'1 was connected to the junction of common line TL by 37½ inches of line T1. The open line stub T4 was 12½ inches in length. The antenna A1 was designed for reception on television channels whose signals extend over a frequency range of fifty-four to eighty-eight megacycles, while the antenna A2 was de-

signed for the reception of signals on television channels having frequencies in the range of 174 to 216 megacycles. Although the antennas shown in Figs. 1 and 3 are indicated as being oriented in the same direction, it should be understood that in practice they may be oriented differently though remaining in parallel horizontal planes. With the arrangement of the invention, one antenna can be oriented differently from the other antenna with a minimum of interference from reflected energy picked up by the other antenna.

Among the advantages of the present invention are:

1. The necessity of running separate transmission lines from each antenna to the receiver is eliminated.

2. The necessity for having a switch to alternately couple the antennas to the receiver when changing from one pair of frequencies to the other is also eliminated.

3. Maximum efficiency from each antenna is achieved while enabling the directivity of the patterns of each antenna to be preserved in different directions, and

4. The construction is simple, easy to build, and inexpensive to make.

What is claimed is:

1. A receiving antenna system comprising first and second dipole antennas of different dimensions spaced apart from each other in different substantially parallel planes, a common transmission line extending to a receiver, branch lines coupling said antennas to a junction point on said common line, the smaller dimensioned dipole being resonant to a frequency F2, the larger dimensioned antenna being resonant to a lower frequency F1, the branch line coupling said larger dimensioned antenna to said common line having an electrical length equal to three-quarter wavelength at frequency F2, the combination of smaller dimensioned antenna and the branch line coupling the same to said common line having an equivalent electrical length which appears as a very high impedance to energy of frequency F1 at said junction point, and an open-ended line stub having an electrical length of one-quarter wavelength at frequency F2 connected at one end to the terminals of the larger dimensioned antenna.

2. A receiving antenna comprising a folded dipole antenna and a larger dipole antenna spaced apart from each other in different substantially parallel planes, a parasitic reflector for each of said antennas, a common transmission line extending to a receiver, branch lines coupling said antennas to a junction point on said common line, the smaller dimensioned dipole being resonant to a frequency F2, the larger dimensioned antenna being resonant to a lower frequency F1, the branch line coupling said larger dimensioned antenna to said common line having an electrical length equal to three-quarter wavelength at frequency F2, the combination of smaller dimensioned antenna and the branch line coupling the same to said common line having an equivalent electrical length which appears as a very high impedance to energy of frequency F1 at said junction point, and an open-ended line stub having an electrical length of one-quarter wavelength at frequency F2 connected at one end to the terminals of the larger dimensioned antenna.

3. A receiving antenna comprising a vertical mast, a folded dipole antenna supported from said mast in a horizontal plane, a larger dipole



antenna also supported from said mast and arranged in a horizontal plane spaced vertically from said folded dipole antenna, a parasitic reflector for each antenna supported parallel to and in the same horizontal plane as its associated antenna, each antenna and associated reflector being positioned on opposite sides of the mast, a common transmission line extending to a receiver, branch lines coupling said antennas to a junction point on said common line, the smaller dimensioned dipole being resonant to a frequency F2, the larger dimensioned antenna being resonant to a lower frequency F1, the branch line coupling said larger dimensioned antenna to said common line, the branch line coupling said larger dimensioned antenna to said common line having an electrical length equal to three-quarter wavelength at frequency F2, the combination of smaller dimensioned antenna and the branch line coupling the same to said common line having an equivalent electrical length which appears as a very high impedance to energy of frequency F1 at said junction point, and an open-ended line stub having an electrical length of one-quarter wavelength at frequency F2 connected at one end to the terminals of the larger dimensioned antenna.

4. A receiving antenna system in accordance with claim 3, characterized in this, that a wooden cross arm supports each antenna and its associated reflector from said mast, and said lines all have a characteristic impedance of 300 ohms.

5. A receiving antenna system comprising first and second dipole antennas of different dimensions spaced apart from each other in different substantially parallel planes, a pair of terminals, branch lines coupling said antennas to said terminals, the smaller dimensioned dipole being resonant to a given frequency, the larger dimensioned antenna being resonant to a lower frequency, the branch line coupling said larger dimensioned antenna to said terminals having an electrical length equal to three-quarter wavelength at said given frequency, the combination of smaller dimensioned antenna and the branch line coupling the same to said terminals having an equivalent electrical length which appears as a very high impedance to energy at said lower frequency at said terminals, and an open-ended line stub having an electrical length of one-quarter wavelength at said given frequency connected at one end to the terminals of the larger dimensioned antenna.

6. A receiving antenna system comprising a folded dipole antenna and a larger dipole antenna spaced apart from each other in different substantially parallel planes, a parasitic reflector for each of said antennas, a pair of terminals, branch lines coupling said antennas to said terminals, the folded dipole antenna being resonant to a given frequency, the larger dimensioned antenna being resonant to a lower frequency, the branch line coupling said larger dimensioned antenna to said terminals having an electrical length equal to three-quarter wavelength at said given frequency, the combination of folded dipole antenna and the branch line coupling the same to said terminals having an equivalent electrical length which appears as a very high impedance to energy at said lower frequency at said terminals, and an open-ended line stub having an electrical length of one-quarter wavelength at said given frequency connected at one end to the terminals of the larger dimensioned antenna.

7. An antenna system comprising first and second folded dipole antennas of different dimensions spaced apart from each other in different

substantially parallel planes, a pair of terminals adapted to be connected to a common transmission line extending to a transducer, branch lines coupling said antennas to said terminals, the smaller dimensioned dipole being resonant to a given frequency, the larger dimensioned antenna being resonant to a lower frequency, the branch line coupling said larger dimensioned antenna to said terminals having an electrical length equal to three-quarter wavelength at said given frequency, the combination of smaller dimensioned antenna and the branch line coupling the same to said terminals having an equivalent electrical length which appears as a very high impedance to energy at said lower frequency at said terminals, and an open-ended line stub having an electrical length of one-quarter wavelength at said given frequency connected at one end to the terminals of the larger dimensioned antenna.

8. A receiving antenna system comprising first and second dipole antennas of different dimensions spaced apart from each other, said antennas being arranged to receive energy of predetermined polarization, a pair of terminals adapted to be connected to a common transmission line extending to a receiver, branch lines coupling said antennas to said pair of terminals, the smaller dimensioned dipole being resonant to a given frequency, the larger dimensioned antenna being resonant to a lower frequency, the branch line coupling said larger dimensioned antenna to said pair of terminals having an electrical length equal to three-quarter wavelength at said given frequency, the combination of smaller dimensioned antenna and the branch line coupling the same to said pair of terminals having an equivalent electrical length which appears as a very high impedance to energy at said lower frequency at said pair of terminals, and an open-ended line stub having an electrical length of one-quarter wavelength at said given frequency connected at one end to the terminals of the larger dimensioned antenna.



9. An antenna system including a pair of terminals, a length of transmission line coupled to said pair of terminals and having an electrical length substantially equal to one wavelength at a given frequency, a dipole antenna resonant to a frequency lower than said given frequency coupled to said length of transmission line at a point three-quarter wavelengths at said given frequency from said pair of terminals, a second dipole antenna resonant to said given frequency, a section of transmission line coupling said second dipole antenna to said pair of terminals, said section of transmission line having an electrical length at which the combined impedance characteristic of said second antenna and said section of transmission line appears at said terminals as a very high impedance to energy at said lower frequency.

JOHN D. CALLAGHAN.


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JFD EXHIBIT 4B.

UNITED STATES DISTRICT CO...
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OFFICIAL COURT REPORTER

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Flat response, does not resonate at high band frequencies.

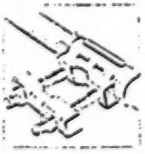
*Wide High and Low Band Reflectors*

Two elements more than similar types, for greater gain.

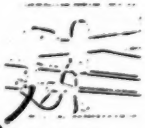
*Self-Tuning Directors on the High Band*

The High Band parasitic elements are twice the length of similar antennas, providing an extra gain boost on channels 7 through 13.

### RUGGEDIZED for longer life



[illegible] "BULLDOG CLIP" MAST CLAMP Rigid steel casting surrounds, protects, and strengthens crossarm. Tighten as much as you want, you can't squeeze or collapse crossarm. Mast is held by two rugged steel jaws which bite into both sides of mast, keep antenna on target even in hurricane-force winds.



"[illegible]" Ingenious device absorbs transmission line tension. Takes pressure off terminals where straining and tearing often cause antenna failure. Stands up under tremendous stress.

[illegible] REFLECTOR Is The longest element, the low band reflector, is reinforced with a ½" diameter insert. This 3½" sleeve ... does the reflector with "shock-proof" reinforcement at the brackets.

[illegible] ... Comes out rain, ... smooth as a ... finish.

[illegible] ... to stop ...

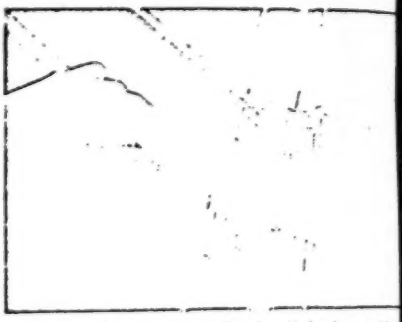
... antenna to ... your ...

**Featuring**

- **Very high front-to-back ratios on the low band**
- **High gain on all VHF channels**
- **Highest quality construction**

Channel Master's new Golden SkyBlazer gives the dealer more performance, more mechanical features, more installation ease, and more economy than any other antenna of similar design.

Yet, despite these big advantages, the Golden SkyBlazer is moderately priced and has achieved great popularity for efficient fringe-area installations at modest cost.



Close-up of driven element bracket. No hardware to tighte...

| Model No. | Description |
|---|---|
| 334-G | 1-Bay |
| 335-3G | Connecting Rods |

Brilliant 2 color printing on sparkling white carton.

[illegible] ... Patent 2,7[illegible]

# CHANNEL MASTER

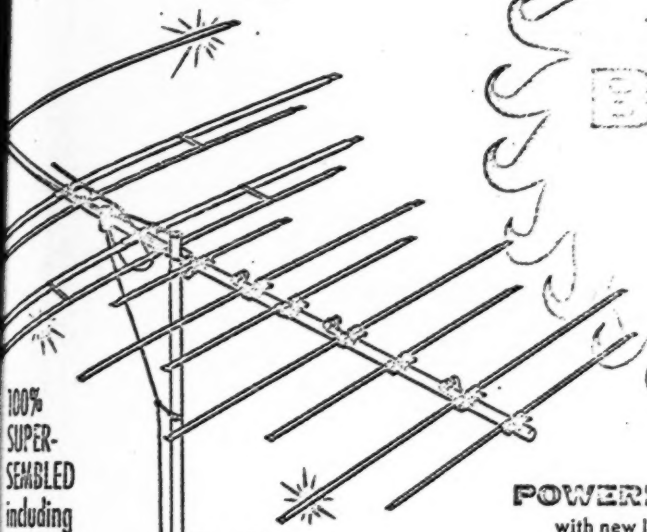
GOLD MEDAL

New Golden

SKY BLAZER

model [illegible]

*All-Channel VHF*
*Fringe-Area Antenna*



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| REV. | DESCRIPTION | DATE | APP. |
|---|---|---|---|
| A | [illegible] | [illegible] | |
| B | ADDED .330 DIA HOLE | 11-6-63 | |
| C | 1/8 THK MAT'L WAS 1/16 THK. | | |
| D | ADDED SPLIT | 5-18-11 | |

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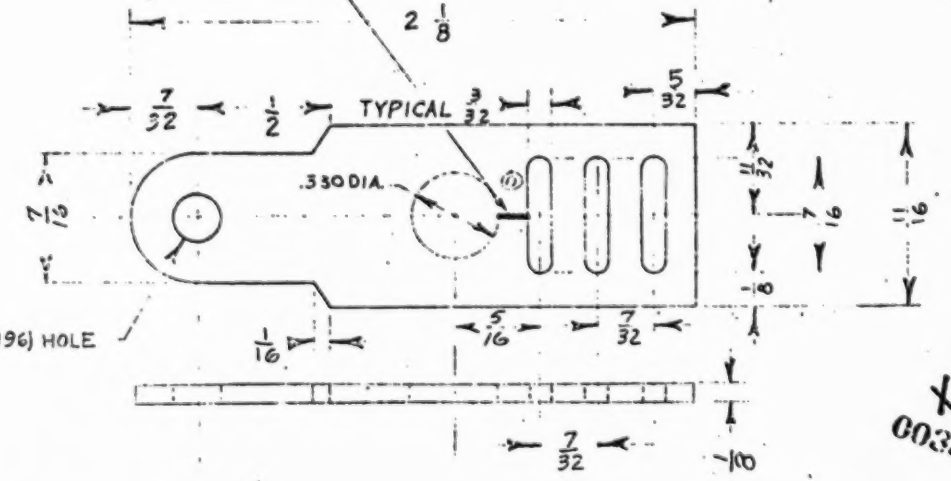


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| ITEM NO. | NO. REQ'D | PART NO. | DESCRIPTION | MATERIAL | SPECIFICATION | NOTE |
|---|---|---|---|---|---|---|

SCALE: 2 X SIZE

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL ± 1/64
DECIMAL ± .005
ANGULAR ± 1/2°

NO. REQ'D PER ASSEMBLY: ~

MATERIAL: POLYETHYLENE

HEAT TREAT. ~

FINISH [illegible]

TWIN LEAD STRAIN RELIEF
ZIP ANT.

| DRAWN | CHECKED | ENG. APP. | PROD. APP. |
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# ANALYSIS AND DESIGN OF THE LOG-PERIODIC DIPOLE ANTENNA

by
Robert L. Carrel

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current on the structure. He first considered planar structures which, if extended to infinity, were self-complementary. This was in order to assure a frequency independent input impedance. Figure 4 shows one such structure which consists of a plurality of teeth and slots cut in a bi-fin in such a manner that the widths of successive teeth and slots form a geometric progression. This self-similar structure was called a log-periodic antenna because its geometry repeats periodically with the logarithm of the distance from the apex. The truncated structure exhibits patterns and impedance which varied periodically with the logarithm of frequency; and for a wide range of parameters the variation over a period was negligible, yielding frequency independent operation. The teeth and slots accomplished the necessary reduction of end effect. The radiation pattern of the planar LP is characterized by a bi-directional beam centered on the $\theta = 0$ axis. The antenna is horizontally polarized when oriented as shown in Figure 4. Thus the polarization of the planar LP is orthogonal to the polarization of the smooth bi-fin.

An attempt at providing a uni-directional pattern led to the non-planar LP structures which Isbell[10] investigated. The antenna shown in Figure 5 exhibits a horizontally polarized uni-directional beam off the tip end. Again, a lack of end effect is observed and the patterns are frequency independent over a range of the design parameters. In the LPD antenna of Isbell[11], shown in Figure 6, dipole elements replace the teeth of the non-planar LP and a constant impedance two-wire feeder replaces the central bi-fin section. One observes the frequency independent behavior of the LPD antenna over large ranges of the design parameters.

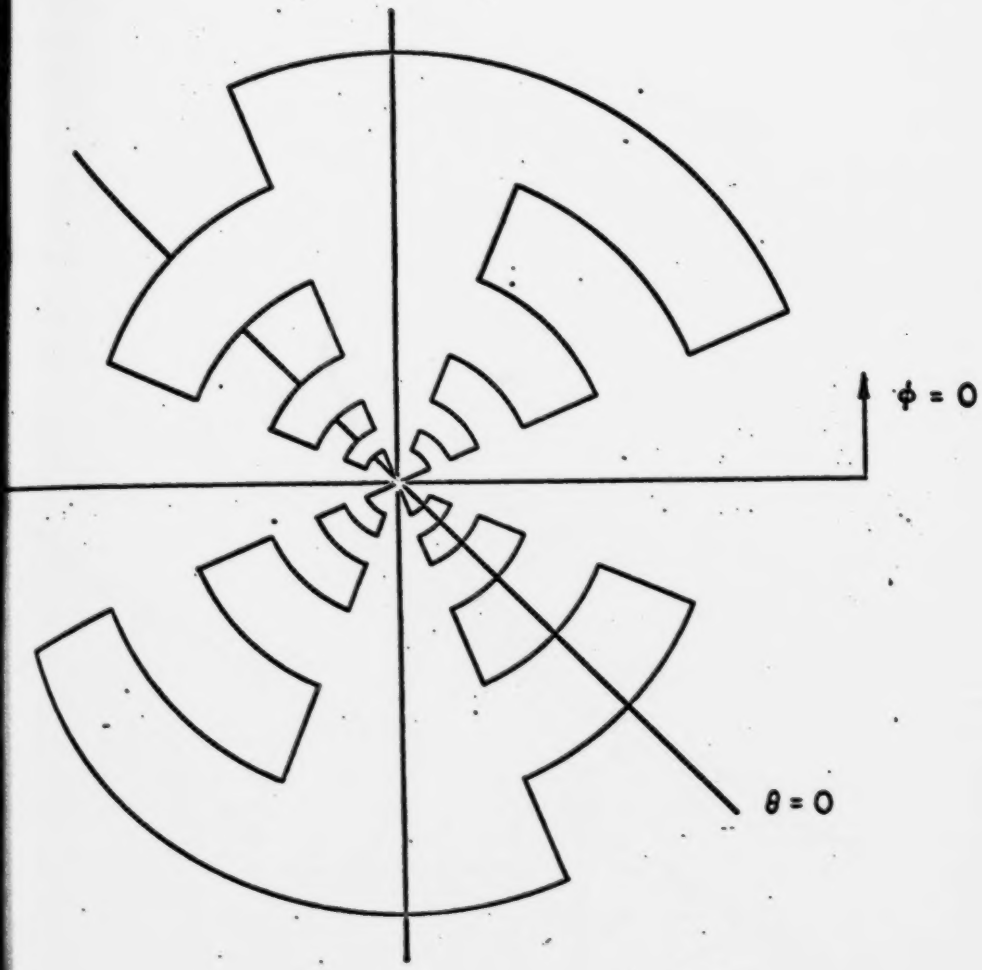



Figure 4. A planar log-periodic antenna

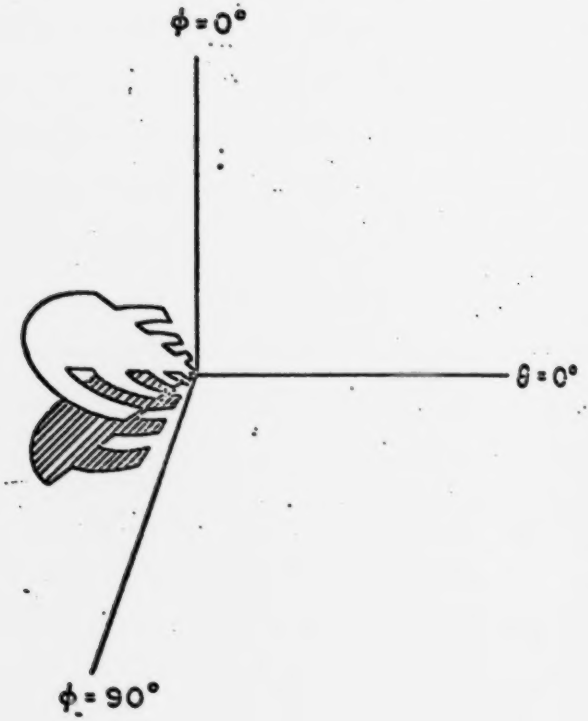



Figure 5. A non-planar log-periodic antenna

Figure 6. A log-periodic dipole antenna

Table 1 summarizes the preceding discussion by a classification of self-similar structures. There are some finite structures that exhibit only log-periodic electrical characteristics and others that have log-periodic geometry but neither frequency independent nor log-periodic performance. Experience has shown that the latter category contains many members.

The log-periodic dipole antenna was selected for analysis because it is made of conventional linear dipole elements, a fact which allows one to replace the tubular conductors with filamentary currents. In this work electromagnetic field theory is used to calculate the self and mutual impedances of the several dipole elements from an assumption of a sinusoidal form of current on each element. Circuit techniques are used to find the voltage and current at the terminals of each dipole element and the antenna input impedance. Once the element current is known, field techniques are again used to calculate the radiation pattern.

The organization of this work is as follows: The preceding section was an introduction to the idea of frequency independent antennas. In Section 2 the mathematical model of the LPD antenna is formulated using the self and mutual impedances of the several dipole elements. The expressions for input impedance, and voltage and current at the base of each element are determined. The equations for the radiated field and the phase center are also set up. In Section 3 the computed and measured results are displayed and analyzed. Criteria for "optimum" LPD antennas are established. Section 4 presents design information, combining the computed and measured results in simple formulas and nomographs. Section 5 summarizes the work. Appended is a section which considers the computation of the equations of Part 2, and a section devoted to the measurement techniques used in this research.

TABLE I

Classification of Types of Structures and Their Frequency Response

C, Constant; FI, Frequency Independent; LP, Log-Periodic; V, Variable

| Geometry of Structure | Examples | Frequency Response | | | |
|---|---|---|---|---|---|
| | | Infinite Structures (no end effects) | | Finite Structures (antennas)* | |
| | | Impedance | Fields | Impedance (range of values) | Pattern (type) |
| Uniform | Bi-Cone<br>Bi-Fin<br>Discone | C | C | V | V |
| Log-Spiral | Planar Log-Spiral | LP+ | LP | FI (50 to 120 ohms) | FI (Bidirectional) |
| | Conical Log-Spiral | LP | LP | FI (100 to 140 ohms) | FI (Unidirectional) |
| Log-Periodic | Planar LP | LP+ | LP | LP (100 to 200 ohms) | FI (Bidirectional) |
| | Non-planar | LP | LP | LP (70 to 165 ohms) | FI (Unidirectional) |
| | LP Dipole | LP | LP | FI (50 to 200 ohms) | FI (Unidirectional) |
| | LP Zig-Zag | LP | LP | LP | FI (Unidirectional) |
| | Other | LP | LP | LP or V | LP or V |

* The response is for frequencies above a minimum value determined by antenna size.

+ It can be shown that these structures have a constant input impedance if they are self-complementary.

## 2. FORMULATION OF THE PROBLEM

### 2.1 Description of the Log-Periodic Dipole Antenna

The log-periodic dipole antenna, shown pictorially in Figure 7 and described by Figure 8, consists of a plurality of parallel, linear dipoles arranged side by side in a plane. The lengths of successive dipole elements form a geometric progression with the common ratio $\tau < 1$. $\tau$ is called the scale factor. A line through the ends of the dipole elements on one side of the antenna subtends an angle $\alpha$ with the center line of the antenna at the virtual apex 0. The spacing factor $\sigma$ is defined as the ratio of the distance between two adjacent elements to twice the length of the larger element, and is a constant for a given antenna. The geometry of the antenna relates $\sigma$ to $\tau$ and $\alpha$.

$$\sigma = \frac{1}{4}(1 - \tau)\cot \alpha \qquad (1)$$

The largest element is called element number 1. The half length of element n is denoted by $h_n$. Therefore,

$$h_n = h_1 \tau^{n-1} \qquad (2)$$

The distance $d_n$ from element n to element n + 1 is given by

$$d_n = d_1 \tau^{n-1} \qquad (3)$$

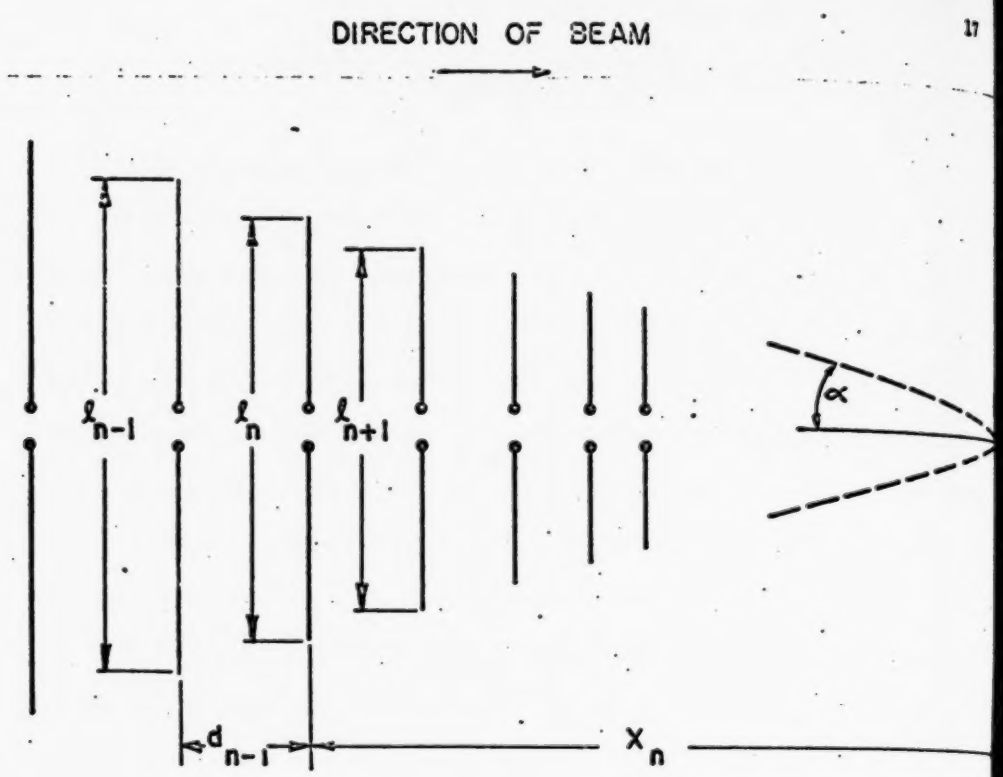
If $a_n$ is the radius of element number n, the $a_n$'s are given by

$$a_n = a_1 \tau^{n-1} \qquad (4)$$

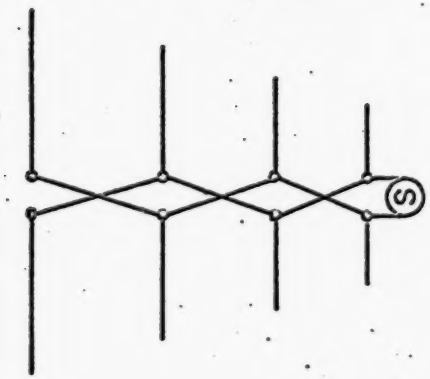
The ratio of element height to radius is the same for all elements in a given antenna and will be denoted by h/a.

The elements are energized from a balanced, constant impedance feeder,

Figure 7. A picture of a log-periodic dipole antenna




$$\frac{X_n}{X_{n-1}} = \frac{\ell_n}{\ell_{n-1}} = \tau \qquad \frac{d_n}{2\ell_n} = \sigma \qquad h_n = \ell_n/2$$




METHOD OF FEEDING

Figure 8. A schematic of the log-periodic dipole antenna, including symbols used in its description

adjacent elements being connected to the feeder in an alternating fashion. Due to the alternating manner in which the elements are connected to the feeder, one cell of the LPD antenna consists of two adjacent dipoles and two sections of feeder. Thus $\tau$ as defined above is the square root of the cell scaling factor. Ideally, the feeder should be conical or stepped, to preserve the exact scaling from one cell to the next. However, it has been found in practice that two parallel cylinders can satisfactorily replace the cones as long as the cylinder radius remains small compared to the shortest wavelength of operation. The element feeder configuration is shown in Figure 9. It is seen that the elements do not lie precisely in a plane; the departure therefrom is equal to the feeder spacing, which is always small.

The antenna may be energized from a balanced twin line connected at the junction of the feeder and the smallest element. Alternatively, a coaxial line may be inserted through the back of one of the hollow feeder conductors. The shield of the coax is connected to its half of the feeder at the front of the antenna; the central conductor of the coax is connected to the other side of the feeder as shown in Figure 9. In the latter method the antenna becomes its own balun because the currents on the feeder at the large end of the antenna are negligible, as will be demonstrated later. Due to the diminution of current at the large end, the impedance $Z_T$ which terminates the feeder at that point is immaterial. For definiteness, in most models $Z_T$ will be taken equal to the characteristic impedance $Z_o$ of the feeder. The propagation constant of the feeder alone is $\beta_o$ and may be different from the free space propagation constant $\beta$ if dielectric is used.

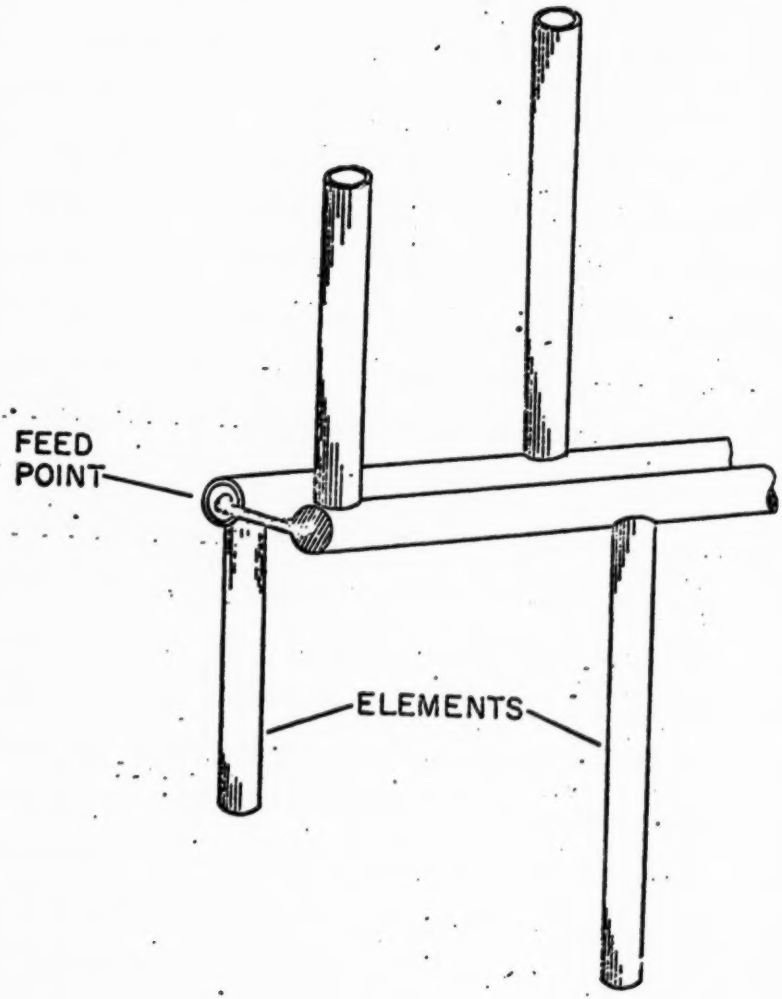



Figure 9. Connection of elements to the balanced feeder and feed point details

computed value; this is because the details of the feed-point geometry
ume additional importance at higher frequencies.

### 3.4.3 Input Impedance as a Function of $Z_o$ and h/a

For fixed $\tau$ and $\sigma$, the mean resistance level is determined by the characteristic
edance of the feeder, $Z_o$. The graph of Figure 41 shows that $R_o$ increases
$Z_o$ increases. The computed points are shown along with the measured values.
addition, points calculated from the approximate formula (71) are also
wn. In all cases the agreement is good, demonstrating the utility of
approximate formula.

Figure 42 shows how $R_o$ depends on $Z_o$ as a function of the mean spacing
tor $\sigma' = \sigma/\sqrt{\tau}$, using the approximate formula (71). As $\sigma'$ increases,
slope of the curves approach unity, indicating that $R_o$ approaches $Z_o$.
The element thickness as given by the ratio h/a can also be used to control
input impedance. Figure 43 shows the effect of changing h/a with fixed
for several values of $\sigma'$. As h/a increases, the loading decreases and
increases.

It can be seen from the preceding graphs that the input impedance of
antennas can be adjusted over a wide range. The upper limit is determined
the problems involved in constructing feeder configurations. Even when
r wire balanced lines are used, characteristic impedances greater than
ohms are difficult to achieve. An added reactance due to the large gap
ween the two halves of each dipole would possibly cause detrimental effects.
the computed models there was no way of taking this into account; the computer
ults show that antennas with $Z_o = 500$ ohms work just as well as antennas
h $Z_o = 100$ ohms. The lower limit of $Z_o$ is determined by the radiating

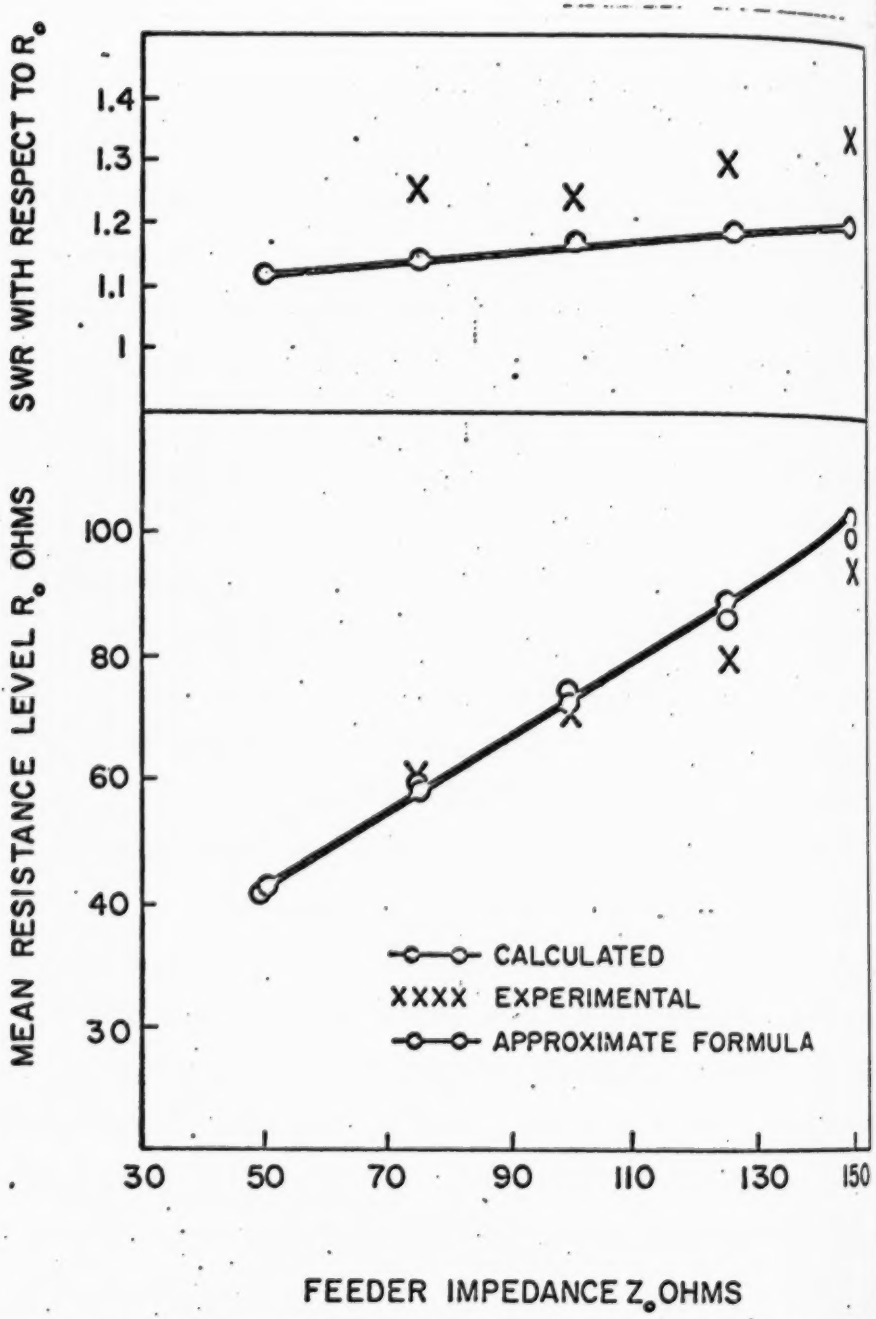
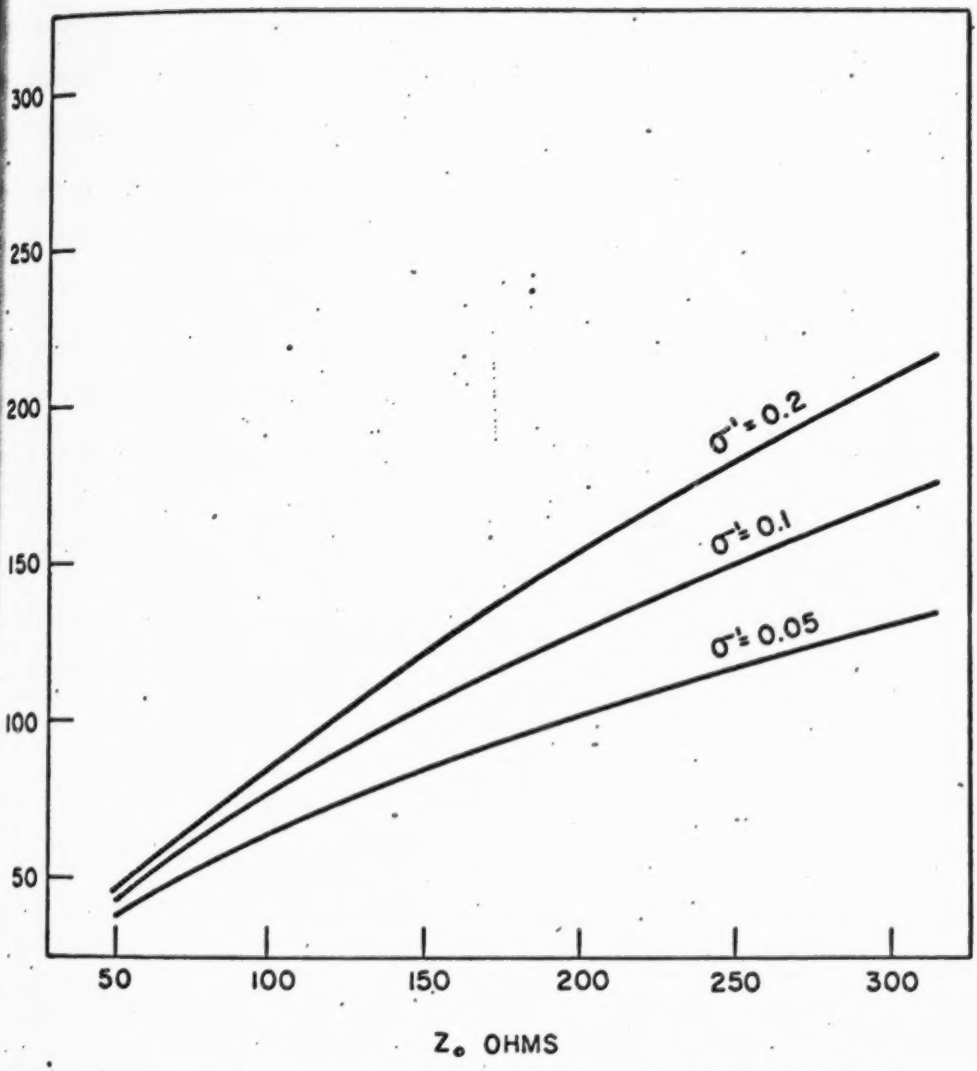



Figure 41. Input impedance $R_o$ vs. feeder impedance $Z_o$, $\tau = 0.888$, $\sigma = 0.089$, $N = 8$, $h/a = 125$.




ure 42. Input impedance $R_o$ vs. $Z_o$ and $\sigma'$ with h/a = 177, from the approximate formula.

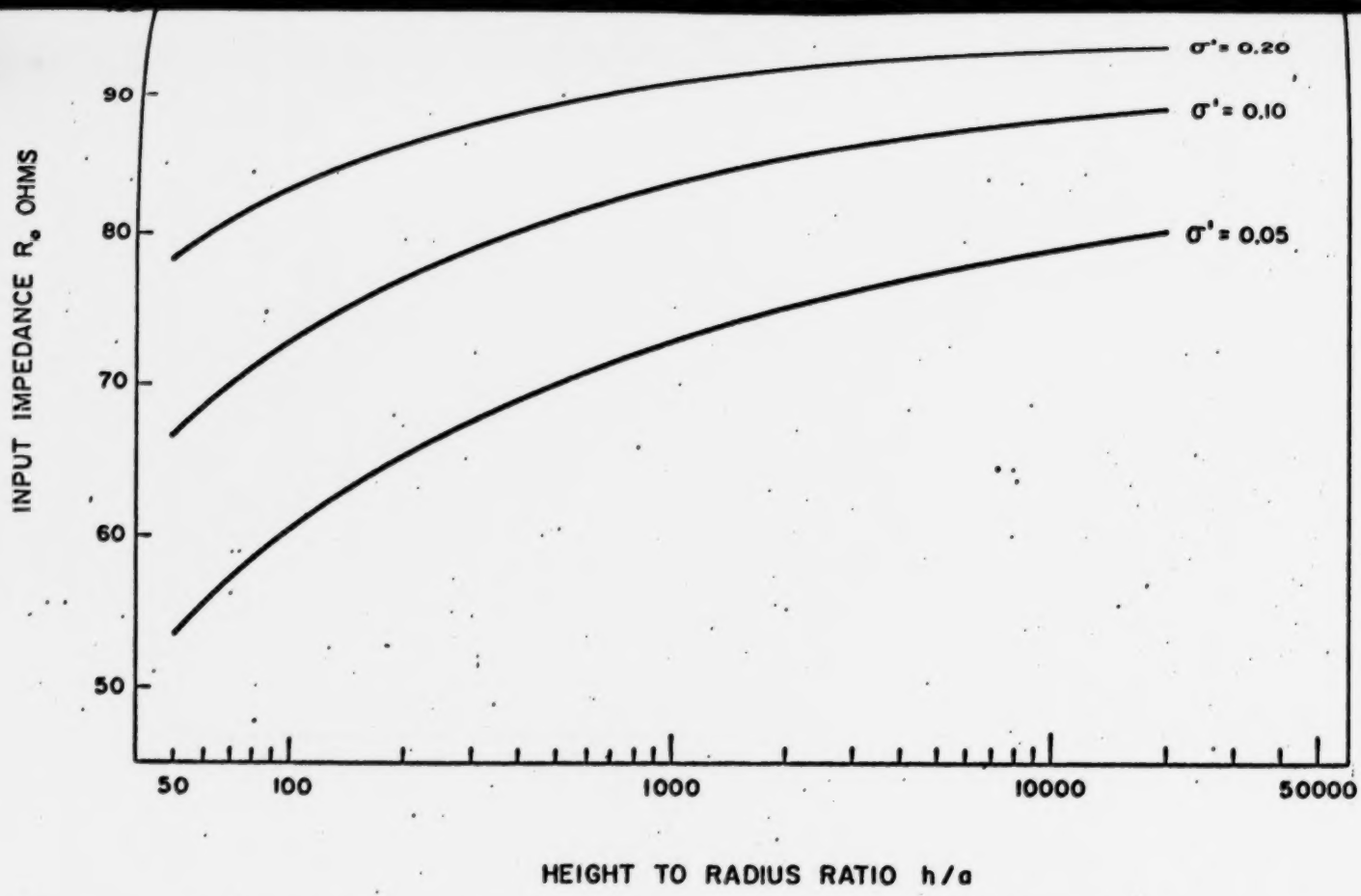



Figure 43. Input impedance $R_o$ vs. h/a and $\sigma$, $Z_o$ = 100, from the approximate formula.

efficiency of the antenna. As previously shown in Section 3.3, in all models in which $Z_o$ is less than 75 ohms an appreciable amount of power remains on the feeder at the large end of the antenna. This power is reflected back through the antenna if the feeder is shorted at the large end, as is commonly done, or it is wasted if a resistive termination is used. This effect has been detected in the computed models. Figure 44a shows the input impedance of an LPD with $Z_o$ = 50 ohms, terminated in a 50 ohm resistor. The impedance locus has the same characteristics as for higher values of $Z_o$. However, when a purely reactive termination is used, the input impedance locus blossoms out as shown in Figure 44b, indicating that the end effect is appreciable. In addition, irregularitites in the pattern occur, otherwise the increased SWR could probably be tolerated.

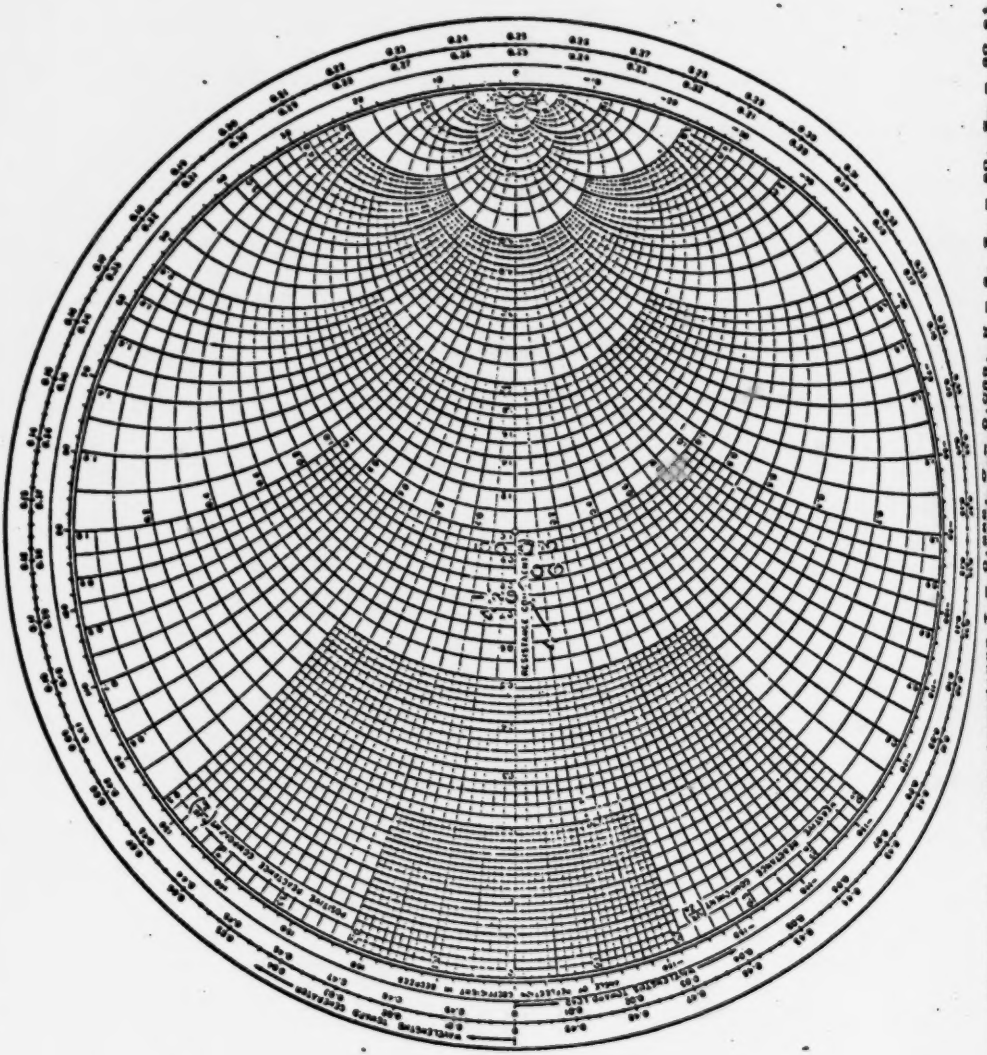
Formula (71) can be inverted to find the feeder impedance required to achieve a given input impedance. In its most useful form $Z_o$ is normalized with respect to $R_o$, resulting in

$$\frac{Z_o}{R_o} = \frac{1}{8\sigma' \frac{Z_a}{R_o}} + \sqrt{\frac{1}{\left(8\sigma' \frac{Z_a}{R_o}\right)^2} + 1} \quad . \tag{73}$$

As in Equation (71) $Z_a$ is the average characteristic impedance of a short dipole, given by

$$Z_a = 120\ (\ln h/a - 2.25). \tag{74}$$

A graph of $Z_a$ versus h/a is given in Figure 45. Figure 46 is a graph of the relative feeder impedance $Z_o/R_o$ versus the relative characteristic dipole impedance $Z_a/R_o$, for several values of the mean spacing factor $\sigma'$. This graph can be used to design for a specific input impedance, given $\sigma'$ and $Z_a$.


RESISTANCE COMPONENTS
REACTANCE COMPONENTS
ADMITTANCE VECTORS
IMPEDANCE VECTORS

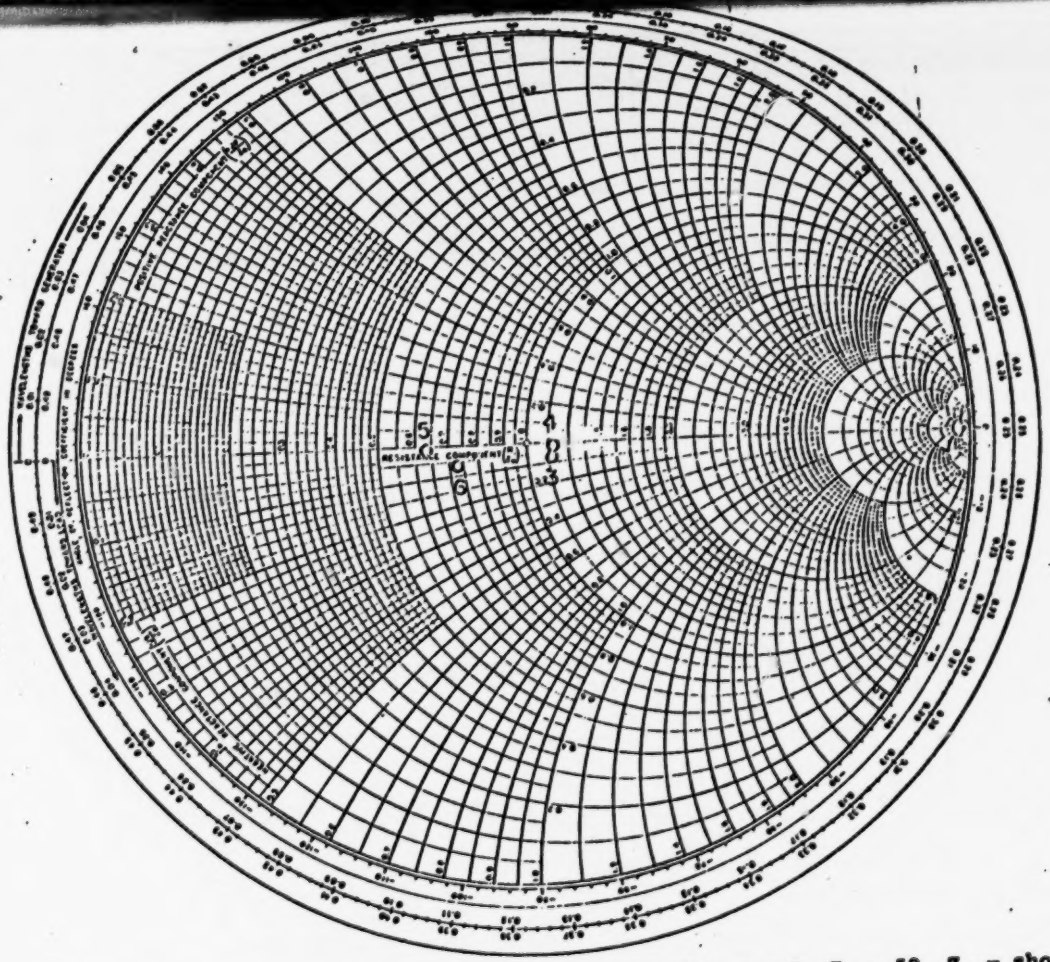


Figure 44b. Input impedance $\tau = 0.888$, $\sigma = 0.089$, $N = 8$, $Z_o = 50$, $Z_T$ = short at $h_1/2$, at frequencies $f_3$, $f_4$, $f_5$ and $f_6$.

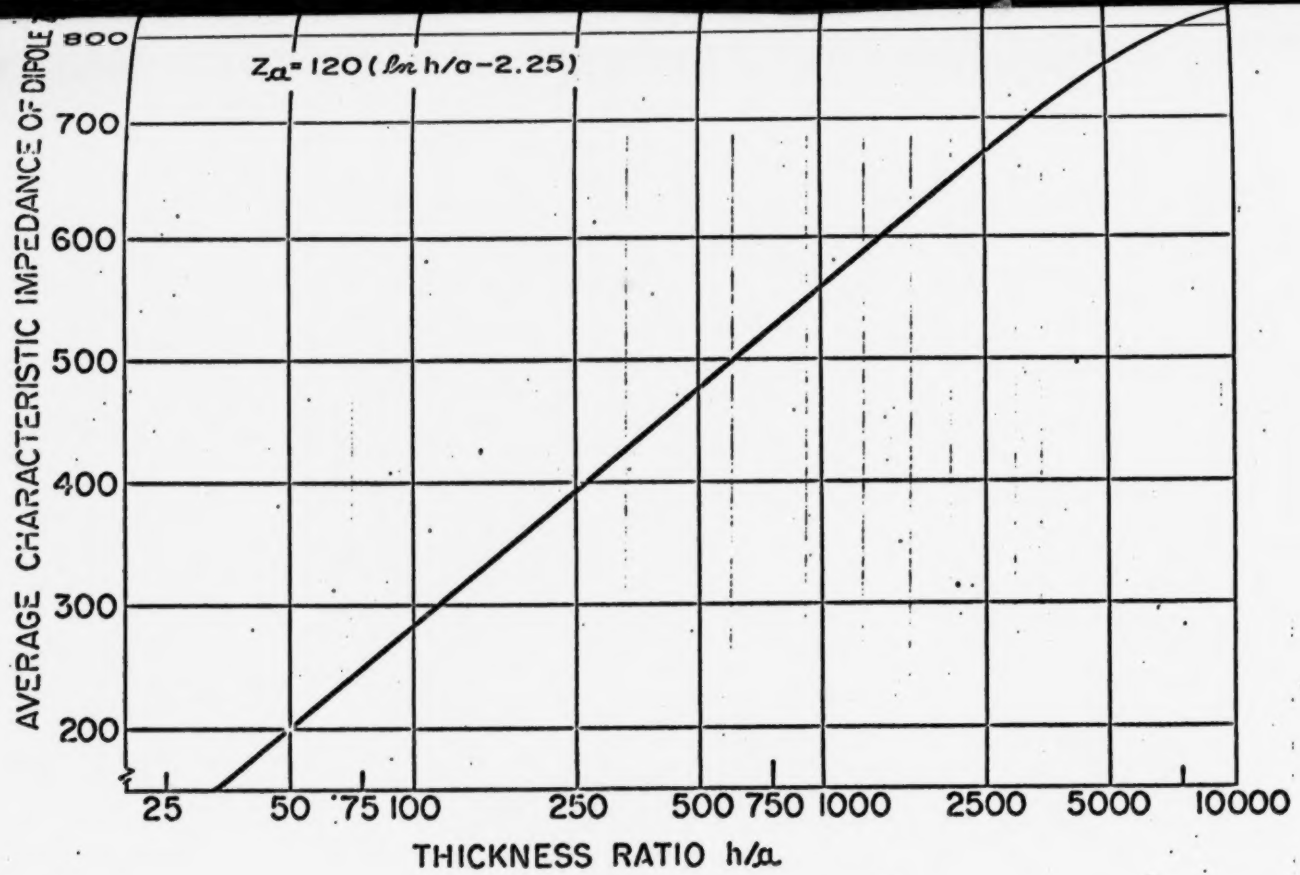





Figure 45. Average characteristic impedance of a dipole $Z_a$ vs. height to radius ratio h/a.

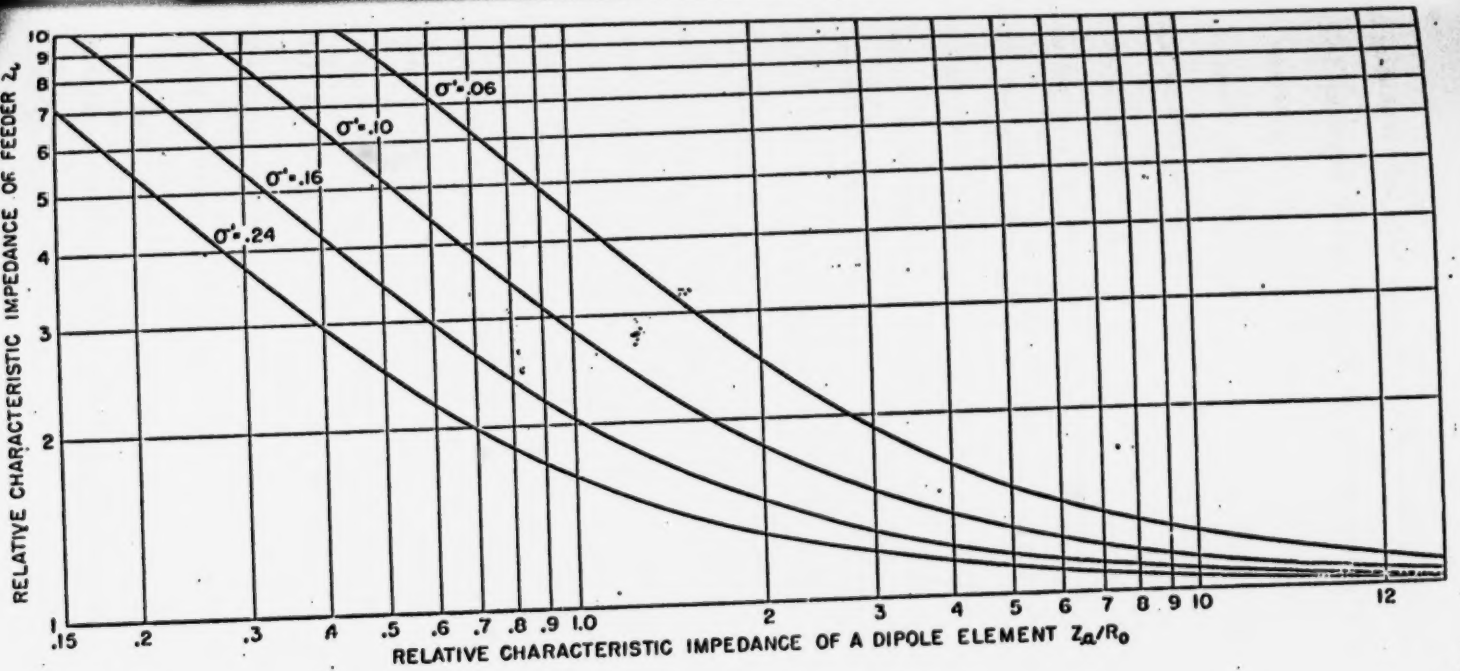



Figure 46. Relative feeder impedance $Z_o/R_o$ vs. relative dipole impedance $Z_a/R_o$, from the approximate formula.

Input impedance levels from 35 to 200 ohms have been measured using the coaxial line feed method pictured in Figure 9. If higher impedance levels are required for use with balanced twin line, the 4:1 balun transformer scheme suggested by Dr. Jordan can be used. In Figure 47, the feeder of an LPD is shown but the elements are not. $R_o$ represents the antenna input impedance at the front end. This load can be driven in parallel by two coaxial lines of characteristic impedance $2R_o$. Each line is inserted through one of the feeders as shown, and at the back of the antenna they are connected in series. A parallel wire line with characteristic impedance $4R_o$ is then connected to the series combination, resulting in a perfect match to the antenna. This balun transformer scheme has a bandwidth equal to the operating bandwidth of the antenna. Since there is no current on the feeder at the back of the antenna, the quarter-wave choke which is ordinarily used in a 4:1 balun is not required, so the balun does not depend on frequency. This technique has been used with success in the design of LPD television receiving antennas.

## 3.5 The Far Field Radiation

The far field properties of the LPD antenna are determined from the equations of Section 2.2.2. This section presents computed results which show how the characteristic pattern of an LPD depends on the various parameters. The characteristic pattern of an LPD is defined as the pattern which typifies the antenna for all frequencies within the design band. The computed patterns are compared with patterns of several experimental models, recorded by the University of Illinois Antenna Laboratory pattern range facilities. Consideration is also given to factors which control the relative phase of the far field. The phase center of an LPD is defined, and measured and com-

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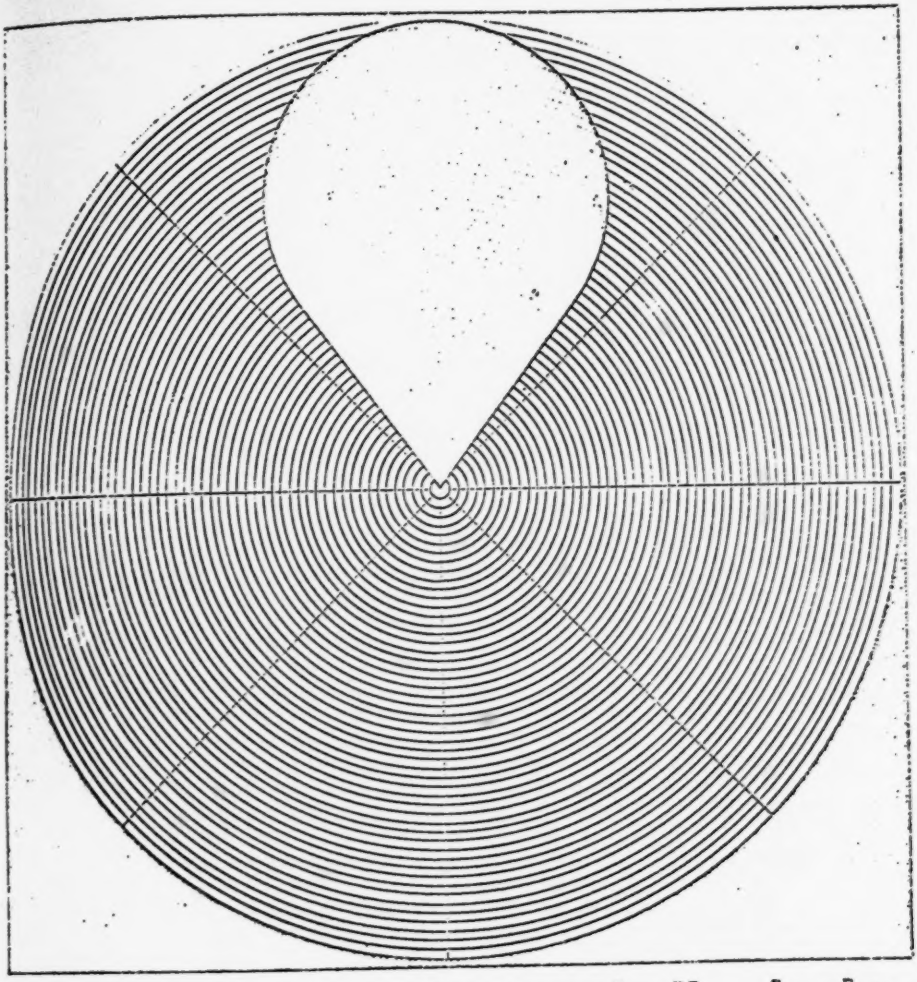
p:1 of X-JFD-23



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# Log Periodic Dipole Arrays*

D. E. ISBELL†

*Summary*—A new class of coplanar line arrays is introduced. The antennas described provide unidirectional radiation patterns of constant beamwidth and nearly constant input impedances over any desired bandwidth. The broad-band properties are achieved by making use of the principles of log periodic antenna design. Models are discussed which are capable of providing 8- to 9-db directive gain with an associated input standing wave ratio of 1:2:1 on a 75-ohm feeder, and this performance is independent of frequency. The free-space properties of several of these arrays have been measured and the results are presented. The antenna configuration is simple, permitting practical methods of fabrication, and the design should prove useful in many applications. It makes possible, for example, the construction of "all-wave" rotatable beams of very low cross section for use in the hf to uhf spectrum.

## I. Introduction

LOG periodic antenna design has been the subject of several papers over the past few years. The concept was first introduced in connection with a plane slot radiator having bidirectional linearly-polarized radiation patterns of constant beamwidth and essentially constant input impedance over better than ten to one bandwidths.[1] Since that time many extensions of the original structure have been introduced providing a large choice of electrical characteristics, all of which are virtually independent of frequency.[2,3] Log periodic antenna designs are available, for example, which provide omnidirectional, bidirectional, or unidirectional radiation patterns and either linear or circular polarization. The basic unidirectional elements all have moderate directive gains, and it has been shown that high gains are possible through application of array techniques[4] or by using the antennas as primary sources for large reflectors.[5,6]

The antennas discussed in the following paragraphs provide electrical characteristics which are similar to those of some of the antennas described in the above referenced papers, but they represent a departure in form. The log periodic designs which have been introduced to date have all been variations of a basic type involving combinations of a single composite element which is shaped to provide the log periodic characteristics. The antennas introduced here demonstrate that the log periodic principles can be applied to the design of arrays of conventional elements with frequency independent performance resulting. An important consequence of this, as will be seen, is that these antennas permit at least a qualitative analysis of their operation in terms of familiar ideas, and they further tend to increase insight with respect to the operation of the original log periodic antennas.

## II. Some General Considerations

Although it has not, as yet, been possible to obtain precise physical understanding of the operation of the successful frequency independent antennas, it is possible to put forth certain qualitative arguments in that direction. The following is an attempt to induce these arguments into the design of a wide-band array using conventional elements.

If frequency independent performance is sought from a structure composed of resonant elements it is clear that the resonances must be staggered in order that as frequency is varied the function of the resonant element is transferred smoothly from one element to the next. In the case of an antenna array composed of similar discrete elements this means that the physical dimensions of the elements must be scaled from one to the next in such a way that the desired frequency range is covered with elements of overlapping response characteristics. Since the characteristics of antenna elements are determined in part by their surroundings, it is necessary also to scale the environment.

Considering now a coplanar array of side-by-side dipoles in accordance with the above ideas, an arrangement of the type shown in Fig. 1 is obtained. The lengths of the dipoles are related by a constant scale factor as defined in the figure. That is, given the length $L$ of the element of order 0 in the array, the length of the elements of order $n$ will be given by $\tau^n L$ where $n$ takes on all integral values, positive or negative. Since it is also necessary to scale the environment, the spacings $\Delta s$ between elements must be related in the same manner. If carried to the limit the array converges to the point 0 on the left as $n \to -\infty$ and becomes infinite in extent on the right as $n \to \infty$. If the elements of Fig. 1

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† Electro-Dynamics Staff, Transport Div., Boeing Airplane Co., Seattle, Wash.

[1] R. H. DuHamel and D. E. Isbell, "Broadband logarithmically periodic antenna structures," 1957 IRE National Convention Record, pt. 1, pp. 119-1280. Also, University of Illinois Antenna Laboratory Tech. Rept. No. 19, Contract AF 33(616)-3220, Wright Air Dev. Ctr.; May, 1957.

[2] D. E. Isbell, "Non-planar logarithmically periodic antenna structures," *Abstracts of the Seventh Annual Symposium on the USAF Antenna Research and Development Program*, October, 1957. Also, University of Illinois Antenna Lab. Tech. Rept. No. 30, Contract AF 33(616)-3220, Wright Air Dev. Ctr.: February, 1958.

[3] R. H. DuHamel and F. R. Ore, "Logarithmically periodic antenna designs," 1958 IRE National Convention Record, pt. 1, pp. 139-151.

[4] R. H. DuHamel and D. G. Berry, "Logarithmically periodic antenna arrays," 1958 IRE WESCON Convention Record, pt. 1, pp. 161-174.

[5] D. E. Isbell, "A log-periodic reflector feed," Proc. IRE, vol. 47, pp. 1152-1153; June, 1959.

[6] R. H. DuHamel and F. R. Ore, "Log periodic feeds for lens and reflectors," 1959 IRE National Convention Record, vol. 7, pt. 1, pp. 128-137.

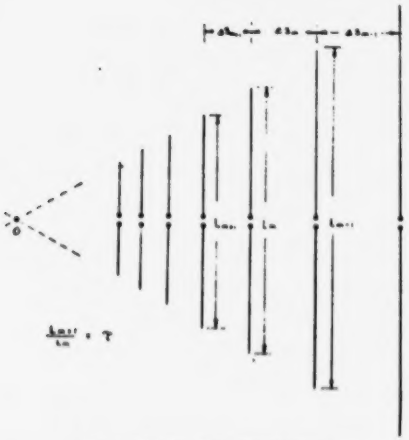


Fig. 1—Side-by-side coplanar array.

are fed in series by means of a common feeder from a generator located at point 0, the infinite structure will possess the property of logarithmic periodicity. That is, whatever the fields produced by an excitation frequency $f$ they will be reproduced (apart from a change of scale) at all other frequencies given by $\tau^n f$. The variation in the fields between these frequencies will depend upon the degree of overlap in the individual element responses.

To be useful as a practical broad-band radiator it must be possible to truncate the array so that at all frequencies above some lower limit the truncated antenna performs like the infinite structure. This imposes a requirement for rapid attenuation of the incident wave along the feeder so that only negligible energy is reflected from the truncated end. If this situation occurs it follows that the array characteristic will be periodic in periods of bandwidth $1/\tau$:1. If, furthermore, the variation in performance is negligible over a period then the antenna may be broad banded to any desired degree by simply adding elements according to the general scheme.

Consideration must now be given to the method of feeding the array. Two methods of introducing the common feeder are shown in Fig. 2. In both cases the dipole elements are attached to the feeder so that their respective terminal impedances appear in parallel across the line at the logarithmically varying intervals $\Delta s$. In Fig. 2(a) the currents in the elements have the same relationship as the terminal phases so that, considering the elements closely spaced, the phase progression of the currents in the array is to the right. In Fig. 2(b), however, the elements are connected so that a phase constant of $\pi$ radians is added to the terminal phase of each element. This is accomplished mechanically by twisting the feeder 180° between each element.

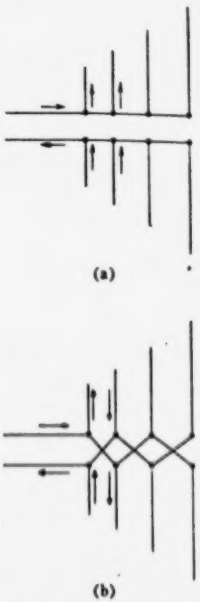



Fig. 2—Two methods of excitation.

A choice between these methods of feeding can be made on the basis of the following reasoning. If the array is to have the property of unlimited bandwidth with constant electrical characteristics, then it is clear that at any given frequency only a portion of the dipole elements can be excited. These elements must be such that the length of the excited portion of the array will be approximately constant in terms of the normalized distance $x/\lambda$ measured from the array vertex. The elements which are not excited by the feeder should make no contribution to the performance so that coupling with the radiated field would be undesirable. It appears then that the radiation pattern of the array should have a null in the direction of the incident energy on the line. It has been pointed out that the array of Fig. 2(a), is fed so that the element phase progresses to the right, and since this type of excitation is a condition for endfire in that direction this would seem to be an unsatisfactory method. Qualitative consideration of the array of Fig. 2(b), however, provides a more promising picture. In this case the short closely spaced elements are seen to be almost in phase opposition and hence radiate very little energy. Further out along the array where the spacing is larger and the elements are longer, the elements will radiate and the mechanical phase reversal effects a reversal in the direction of phase progression so that the radiation pattern is endfire in the direction of the input terminals. With this method of feeding, the

elements which radiate the most energy will be those near resonant lengths and their combined radiation pattern is toward the array apex as desired. As the frequency is increased the radiating elements appear closer to the apex of the array by an amount proportional to the change in wavelength so that the normalized array length remains approximately constant as the frequency is varied.

An experimental program was carried out to determine the electrical properties of arrays of the type shown in Fig. 2(b), and it was found that this antenna, for certain parameter values, has essentially frequency independent performance over any desired bandwidth.

## III. Experimental Results

### A. Model Description

The parameters describing the experimental arrays are shown in Fig. 3. The structure is defined in terms of the geometric ratio $\tau$, the angle $\alpha$, and the characteristic impedance of the feeder. The feeder impedance has not been found to be critical, and for most of this investigation 105 ohm, rigid, open wire line was used. The method of obtaining the 180° phase reversal between elements is shown in the sketch of Fig. 4. The array is fed by means of a coaxial cable brought to the input terminals through one of the balanced line conductors. No balun is required for this method of feeding.

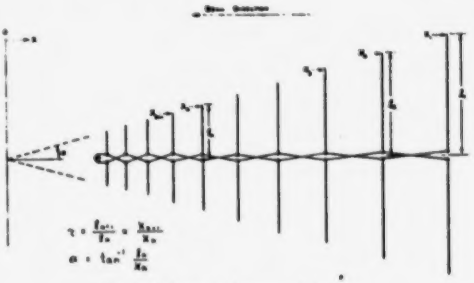


Fig. 3—Schematic diagram of the array.

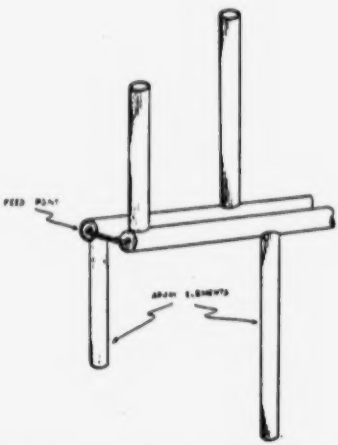


Fig. 4—Connection of elements to balanced feeder.

### B. Effect of Truncation

One of the first things to be determined experimentally is the effect of truncation of the array. It is necessary that the electrical properties of the truncated structure converge to characteristic values as the frequency is increased. As previously mentioned, it should be the case that above some low-frequency limit, determined by the maximum physical dimension of the array, the properties are identical to those of the infinite structure.

If the antenna array is thought of as a linear-passive four-terminal network with input terminals at the apex and output terminals at the truncated end then it may be considered as shown in Fig. 5. It is required that for the truncated antenna, the transmitted power $P_t$, through the network, be only a negligible part of the net power input, $P_i - P_r$. In other words, the transmission coefficient $S_{12}$ of the network, must be small. It is essential that the antenna configuration convert, efficiently, the power incident on the feeder to radiated power $P_R$. The radiating efficiency is defined as

$$\eta_R = \frac{P_R}{P_i - P_r}.$$

In terms of the scattering coefficients this becomes

$$\eta_R = \frac{1 - |S_{11}|^2 - |S_{12}|^2}{1 - |S_{11}|^2}.$$

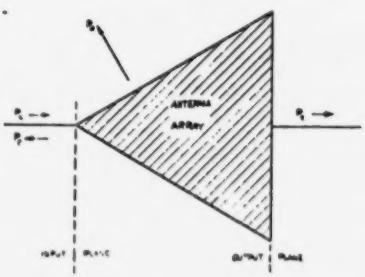


Fig. 5—The array as a two-port network.

Note that the efficiency so defined does not take into account the conductor losses in the elements, and is therefore the true radiating efficiency only in the lossless case.

A simple method of determining the scattering parameters of a two-port network was introduced by Deschamps.[2] With this method, the image of the unit circle in the output plane is determined experimentally and plotted in the input reflection coefficient plane. This is accomplished by a simple series of slotted line measurements of the input reflection coefficient as a function of pure reactive terminations at the output terminals. Determination of the unit image circle and its iconocenter is sufficient for determination of the scattering matrix elements.

The experimental apparatus for making this measurement is shown in Fig. 6. The individual antenna elements were made from thin copper strips formed at one end so that they snap in place on the conductors of the open wire line. This procedure was found to be both simple and satisfactory although care was necessary in making the elements to ensure that they stood perpendicular to the feeder. The pure reactive termination was obtained with a sliding short on the balanced line beyond the antenna elements.

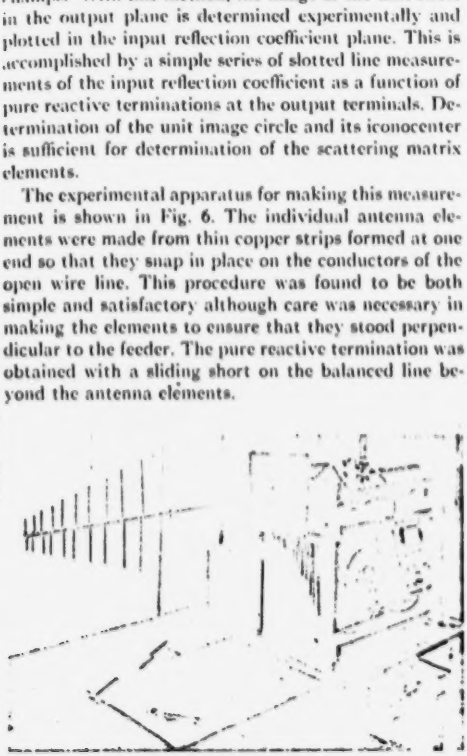


Fig. 6—Measurement apparatus.

The radiating efficiency was measured for several of the arrays as a function of size. This was accomplished by starting with a few small elements near the apex in place and then measuring the scattering coefficients of the network as each additional element was snapped in place. A curve of radiation efficiency as a function of array size is shown in Fig. 7 for one of the models tested. Notice that by the time an element of length $\lambda/2$ is added nearly 80 per cent of the power is being radiated.

[2] G. A. Deschamps, "Determination of reflection coefficients and insertion loss of a waveguide junction," *J. Appl. Phys.*, vol. 24, pp. 1046-1050; August, 1953.

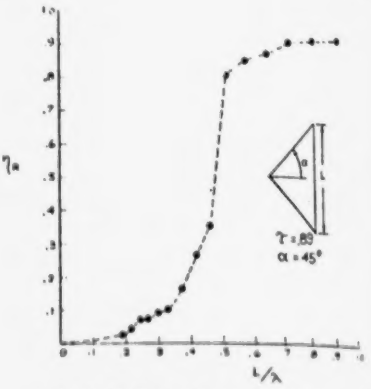



Fig. 7—Radiating efficiency vs antenna size.

### C. Input Impedance

The input impedances of the experimental models were measured using the same set up as shown in Fig. 6. The array elements were arranged so that the terminals of the shortest dipole appeared at the junction between the coaxial cable and the balanced line. This procedure effectively truncates the array at both ends providing upper and lower frequency limits accordingly. Between these frequency limits the input impedance was found to behave in a manner characteristic of the design parameters $\tau$ and $\alpha$, and several combinations were investigated.

The results of the impedance measurements are shown in Figs. 8-10. Each figure shows the variation of the input impedance as a function of $\alpha$ for a given value of $\tau$. The solid curve represents the approximate mean resistance level $R_0$ of the impedance locus and the dashed curve shows the corresponding voltage standing wave ratio with respect to $R_0$. If, for example, a 75-ohm coaxial cable is used to feed an array having $\tau = 0.9$, $\alpha$ of approximately 17°, then the resulting standing wave ratio on the line will be about 1.2:1 over any desired range, depending on the locations of the two truncations. All impedances were measured with the balanced feeder terminated in a short circuit a distance $l_1/2$ beyond the largest element.

### D. Radiation Patterns

The characteristic radiation pattern is an end-fire beam in the negative $x$ direction, as indicated in Fig. 3. The beamwidths are nearly constant in both principal planes and the directivity is a function of both $\tau$ and $\alpha$. It is not, therefore, possible to control the pattern independently of the input impedance, but it should be possible to make satisfactory compromises when selecting parameters.

Radiation patterns were measured for the same range of parameters as were the impedances. Figs. 11-13 show how the characteristic radiation patterns vary with $\alpha$ for three values of $\tau$. The estimated directive gain as a function of $\alpha$ is shown in Fig. 14. Cross polarization for these antennas is considerably better than 20 db below pattern maximum, if care is taken with regard to mechanical symmetry. Pattern measurements, like the impedance measurements, were made with the balanced feeder terminated in a short circuit a distance $l_1/2$ beyond the terminals of element $l_1$.

### E. Bandwidth Control

Since the log periodic dipole array may be truncated at both ends and still provide nearly frequency independent performance over some range of frequencies, it is clear that, in the interest of saving size and weight, a particular antenna should be designed to meet the minimum required bandwidth. The upper and lower frequency limits will be determined by lengths of the shortest and longest elements of the array respectively.

To determine this bandwidth for a particular array the antenna shown in Fig. 13 was constructed. This antenna is defined by a $\tau$ of 0.95, $\alpha$ equal to 10°, $l_1$ equal to 2½ inches, and the shortest element half the length of the longest. The array is 7½ inches long and there are a total of fifteen dipoles included.

Radiation patterns for this array are shown in Figs. 16-18 over the band 1100 to 1800 mc, and the directive gain, estimated on the basis of half-power beamwidth, is shown in Fig. 19. The minimum front-to-back ratio is 17 db and the directivity is better than 9 db over isotropic from 1130 to 1750 mc. The variations in the directivity curve correspond closely to the periodicity $\tau$.

A scaled-up model of the array was assembled on the balanced line of the impedance measuring set up of Fig. 6, and its input impedance was measured over a range corresponding to that of the radiation patterns above.

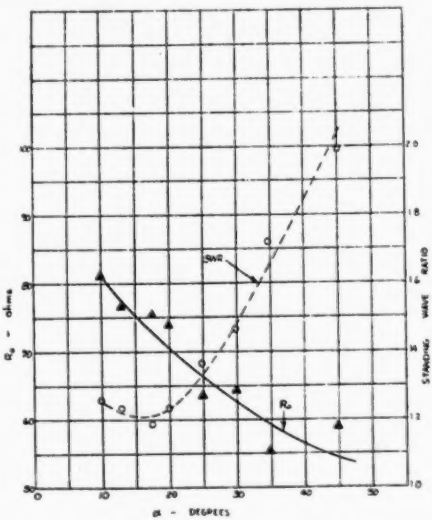



Fig. 9—Input impedance; $\tau = 0.89$.

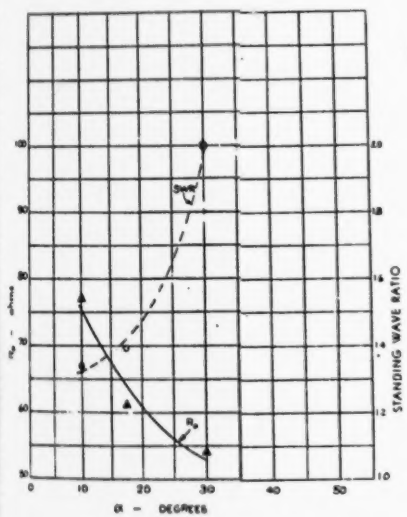



Fig. 8—Input impedance; $\tau = 0.95$.

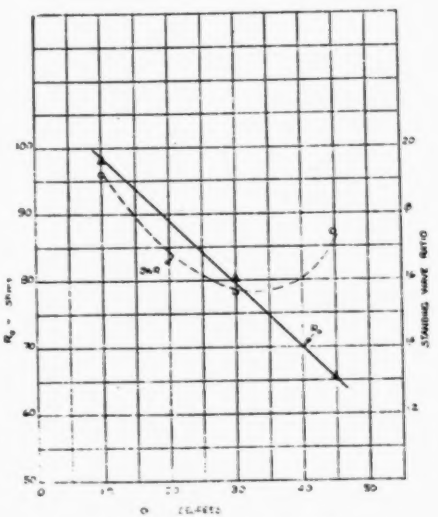



Fig. 10—Input impedance; $\tau = 0.81$.

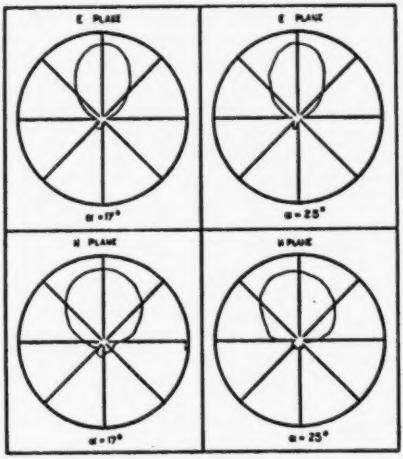



Fig. 11—Typical field patterns; $\tau = 0.95$.

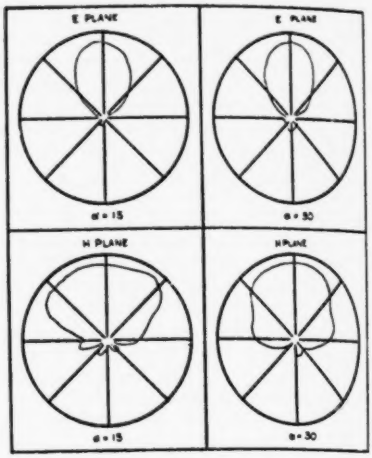



Fig. 13—Typical patterns; $\tau = 0.81$.

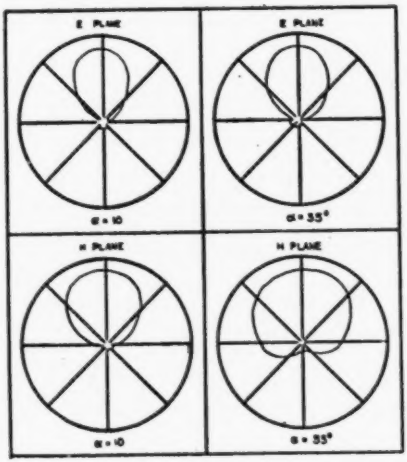



Fig. 12—Typical field patterns; $\tau = 0.89$.

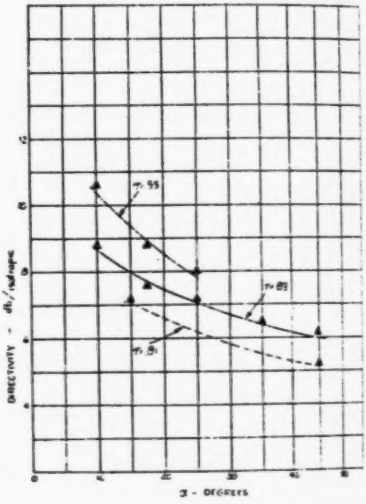



Fig. 14—Directivity vs $\tau$ and $\alpha$.

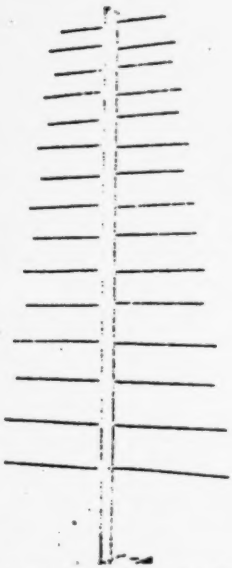


Fig. 15—Bandwidth control model.

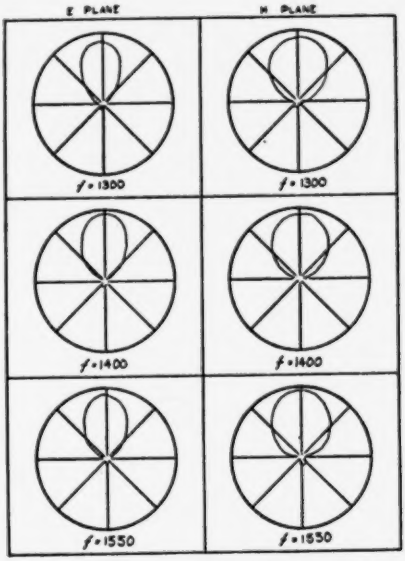



Fig. 17—Field patterns of bandwidth control model.

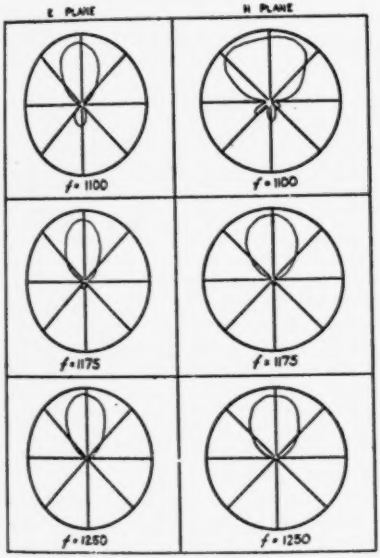



Fig. 16—Field patterns of bandwidth control model.

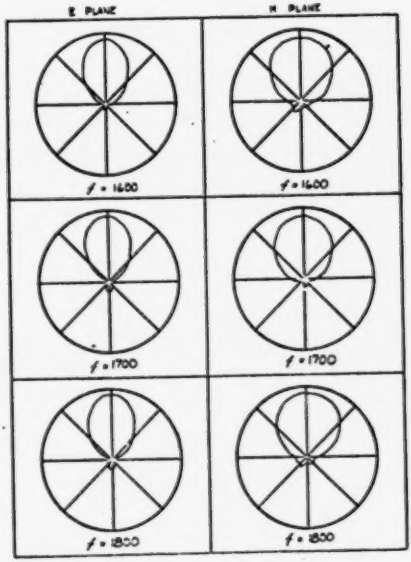



Fig. 18—Field patterns of bandwidth control model.

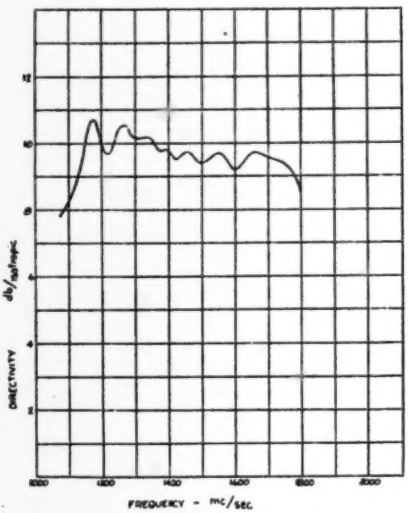



Fig. 19—Directive gain of bandwidth control model.

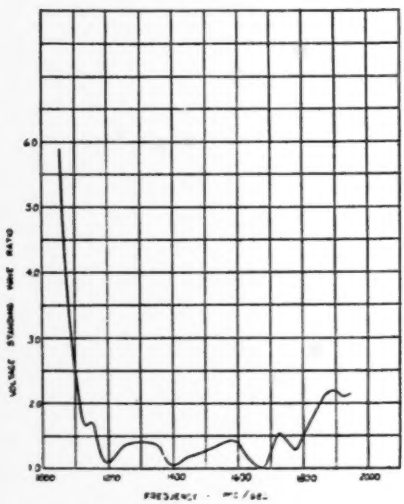



Fig. 20—VSWR with respect to 72 ohms.

The results of this measurement are shown in Fig. 20 in terms of the standing wave ratio produced on a 72-ohm transmission line.

If the usable bandwidth of this antenna is taken to be the range from 1100 to 1800 mc then the size of the antenna for any desired bandwidth is defined. That is, the longest dipole element should be approximately 0.47 frequency long at the lower limit and the shortest element should be about 0.38 wavelength long at the higher wavelength. There will, of course, be some minimum number of elements necessary to provide a suitable front to back ratio at the low frequency limit.

## IV. Conclusions

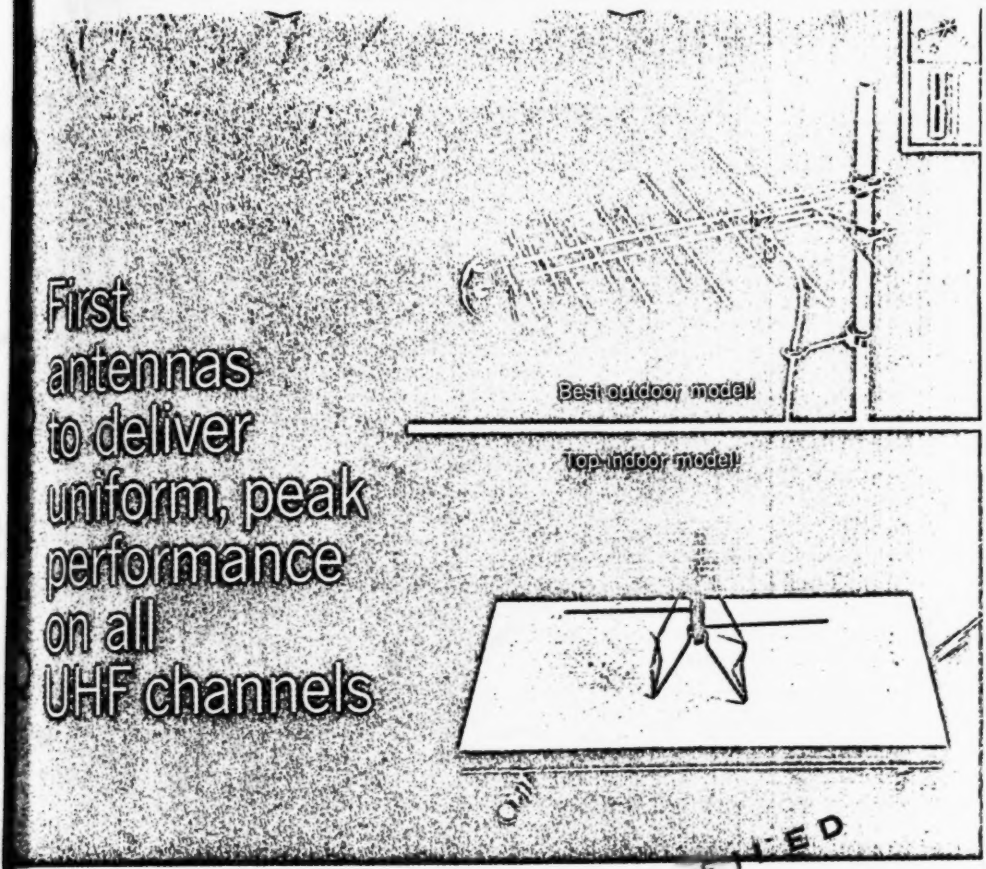
The arrays discussed in the foregoing paragraphs should prove useful in several applications. The model used to demonstrate bandwidth control shows that these antennas will make excellent rotatable beams, superior in many respects to the parasitic types currently in use. It is interesting to compare, for example, the antenna of Fig. 15 to a 5-element Yagi.

A wide-spaced five-element Yagi adjusted to provide a midband front-to-back ratio of 25 db, will provide a 7 per cent bandwidth with a front-to-back ratio of approximately 15 db at the edges. The midband directive gain of this antenna is slightly better than 10 db over isotropic, and its length is about 0.85 wavelength. The log periodic beam of Fig. 15 has fifteen elements but is only 0.73 wavelength long at the low-frequency end. The directivity stays above 9 db with the front-to-back ratio better than 17 db through a bandwidth of 43 per cent, and the elements need no adjusting for this performance.

DuHamel and Berry have shown that the original log periodic elements can be arrayed to provide directivities of up to 20 db, and those same principles may be applied to the dipole array where higher gains are required. Omnidirectional horizontal polarization and unidirectional circular polarization should be achievable by using the methods introduced by DuHamel and Ore.

In addition to the practical usefulness of the log periodic dipole arrays there is another equally interesting and important aspect of the design. The fact that these structures are made up of conventional linear elements seems to invite analysis in terms of familiar transmission line and array theory. To be sure, the problem is not a simple one even so, but its solution would be well worth while in the study of frequency independent antennas. This problem is presently being considered.

COUNTER-DEFENDANT EXHIBIT JFD-23.

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## BLONDER-TONGUE UHF ANTENNAS
## GOLDEN DART outdoors/GOLDEN ARROW indoors

These Blonder-Tongue antennas take advantage of today's most modern approach to TV antenna design —the periodic principle. Result: they provide constant high gain with matched impedance on all channels from 14 to 83.

**ALL-CHANNEL REALLY MEANS ALL-CHANNEL**

No matter what UHF channel serves your area from 14 to 83, the Golden Dart and the Golden Arrow deliver sharp, clear pictures on every one. The reasons: an excellent front-to-back ratio; sharp directivity to minimize ghosts and other interference; and a low VSWR.

**EXCELLENT FOR COLOR OR BLACK AND WHITE TV**

Full bandwidth, flat response for sharp black & white and brilliant, true fidelity color pictures.

**ENGINEERED BY THE COMPANY WITH THE MOST UHF EXPERIENCE**

The same know-how employed in producing 3 million UHF converters has gone into making the finest UHF antennas in the field. By providing peak performance across the full UHF spectrum, they match the high performance standards of Blonder-Tongue UHF converters.

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# UHF GOLDEN DART
## Outdoor Periodic Antenna

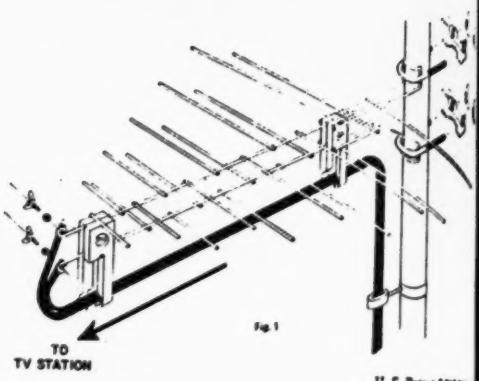


Fig. 1

U. S. Patent 3048[illegible]
Foreign Patents
Patent Pending.

### INSTALLATION INSTRUCTIONS

1. Mount antenna as shown in Fig. 1.
2. Assemble thumb screw and stripless washer on the flat side of the threaded stud.
3. Slit twin lead and flatten or trim end to fit under stripless washer. Note: Low loss foam filled UHF lead is recommended.
4. Tighten thumb screw and check to see that stripless washer pierces insulation and makes contact with wire.
5. Snap twinlead into insulating fingers and use a standoff close to the antenna as shown.

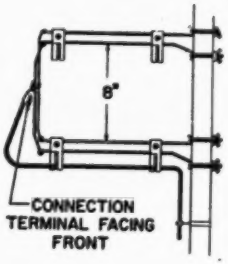


Fig. 2

### For Weak Signal Areas Stack Two Darts With Kit 3519

1. Attach stacking bars as shown in Fig. 2.
   Note: bars are attached by sliping over hollow threaded studs on antenna. See Fig. 3.
2. Attach downlead to center of stacking bars and dress thru insulators on bottom Dart, as shown in Fig. 2.

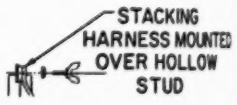


Fig. 3

### ASSOCIATED EQUIPMENT

1. ABLE U-2 — High gain all channel transistorized 300 ohm mast mounted UHF amplifier.
2. UHF-2 — UHF Line splitter to feed two TV sets from one antenna or to connect two Darts facing different directions into one down lead.
3. A-107 — Use to combine signals from UHF and VHF antenna as well as splitting UHF-VHF signals from one down lead.
4. CMB-92U — Use to run 75 ohm shielded cable in high interference areas.
5. Complete line of UHF converters for the home and for Master Antenna Systems.

**LOOK TO B-T AS THE LEADER IN UHF RECEPTION AIDS**

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9 Alling St., Newark, N.J.

Canadian Div.: Benco Television Assoc., Ltd., Toronto, Ont.

*home TV accessories • UHF converters • master TV systems*
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B-T (5)

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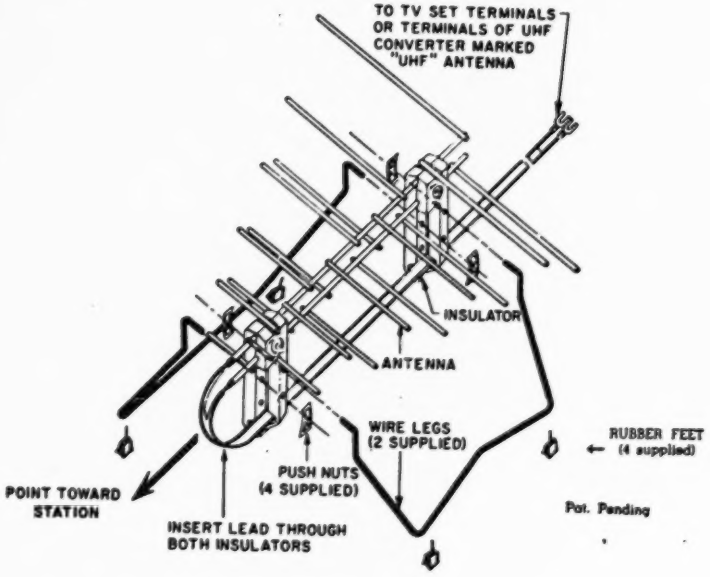
# BLONDER – TONGUE

176

# GOLDEN ARROW

## INDOOR UHF ANTENNA




## ASSEMBLY INSTRUCTIONS

Check contents for the following:

A. (1) antenna assembly (with attached twinlead)
(2) wire legs
(4) push-nuts and (4) rubber feet (enclosed in plastic bag)

B. Insert lead through both insulators, as shown.

C. Install wire legs, as shown. (Be sure to use top holes of insulator).

D. Attach rubber feet as shown.

E. If T.V. set has built in UHF tuner, attach lugs of antenna lead directly to terminals on set marked "UHF" antenna. If a UHF converter is employed, install converter following the manufacturers instructions. Attach lugs of antenna to terminals of converter marked "UHF Ant".

## POSITIONING THE ANTENNA

Best results are obtained by the **careful** tuning of UHF T. V. set or T. V. set/converter in combination with the correct positioning of the antenna toward the T. V. station. Face short-element side of antenna toward T. V. station. Follow manufacturers instructions for tuning UHF T. V. set or T. V. set/converter. **Slowly** rotate antenna for best picture and sound. Quality of reception may possibly be improved by a slight re-tuning of the T. V. set fine tuning control.

**LOOK TO B-T AS THE LEADER IN UHF RECEPTION AIDS**

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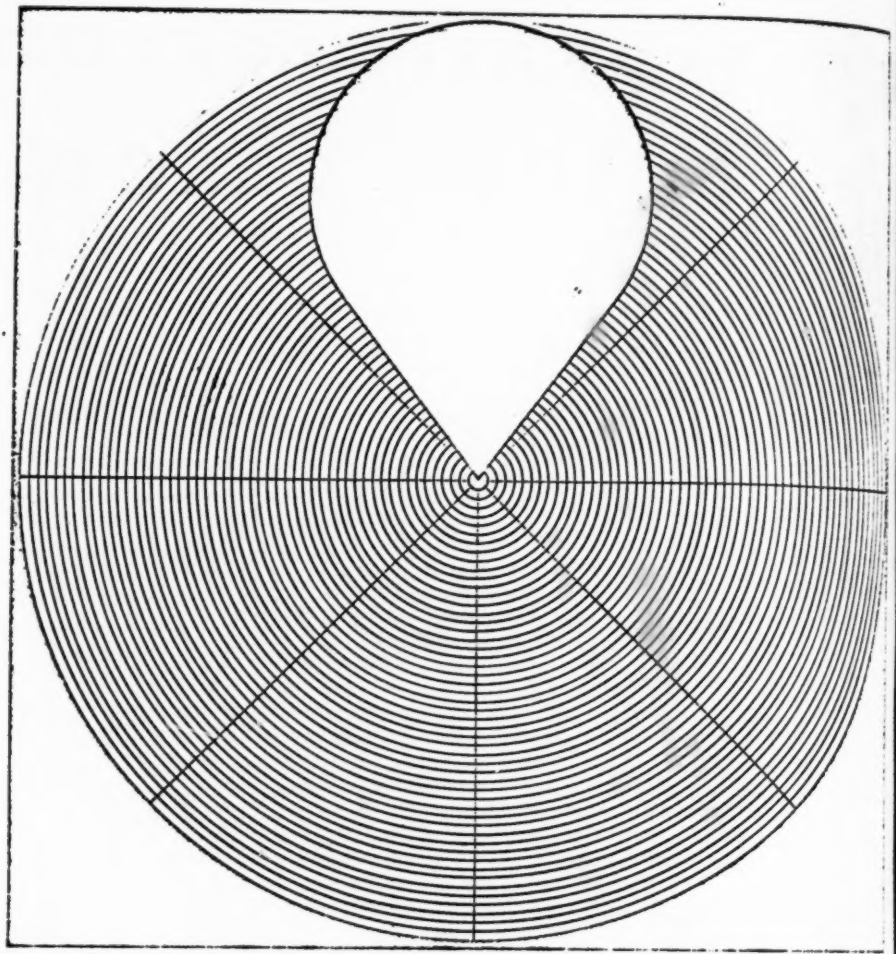


# New look in true log periodic design

## The new Blonder-Tongue color ranger antenna line

NEW... Install VHF now... Add UHF later... No couplers required... It's convertible!

NEW... UHF add-on acts as a VHF signal director (improves VHF signal reception)!

NEW... True log periodic design for constant gain across the entire bandwidth (no station dropouts).

NEW... Built-in support for downlead protection.

NEW... Light weight... Can be installed by one man.

APPROVED FOR COLOR

# The new Blonder-Tongue color ranger antenna line

## U-Ranger

**Eleven-Element**
**True Log-Periodic UHF**
**Add-On Antenna**

Superb reception of black-and-white and color TV. Improves VHF reception of Color Ranger antennas for any signal area. Attaches in seconds to all Blonder-Tongue Color Ranger antennas. No couplers and only one downlead needed for VHF/FM and UHF.

## Color Ranger-3

**Three-Element**
**True Log-Periodic Antenna**

For metropolitan and suburban use. Outperforms dipoles, flying V's, and conicals. Excellent for color TV and FM stereo. Recommended for strong signal areas where ghosts are not a major problem. Add UHF with the U-Ranger.

## Color Ranger-5

**Five-Element**
**True Log-Periodic Antenna**

Outstanding metropolitan and suburban antenna. Superb reception of color TV and FM stereo. Performs better than stacked flying V's and conicals. Superior to most small yagis. Recommended for strong-to-medium signal areas and *for all but the most severe cases of ghosting.* Add sparkling UHF with the U-Ranger.

## Color Ranger-10

**Ten-Element**
**True Log-Periodic Antenna**

Superior metropolitan, suburban and fringe-area reception. Outperforms yagis and even many large antenna arrays. Brilliant reception of color TV and FM stereo. Recommended for all signal areas, especially those with weak signals, or where ghosts are a severe problem. Add crystal-clear UHF with the U-Ranger.

**NOW** . . . the first TRUE log periodic antenna . . . the new Color Ranger . . . outperforms other antennas in any reception area. It is particularly effective for color or where ghosting is a problem because it has:

1. Uniform gain across entire band for brilliant color reception.
2. Best front to back ratio in the industry for outstanding reception in weak signal areas and positive ghost-killing power.
3. Uniform impedance across entire band.

**IT'S CONVERTIBLE, TOO!** The Color Ranger VHF antenna converts to UHF/VHF instantly and at any time, now or as needed for new UHF stations coming on the air, with the U-Ranger add-on. No couplers, no extra downlead required! One lead carries VHF/FM and UHF signals.

## And only the Blonder-Tongue Color Ranger offers all these outstanding features:

**Electrical Features:**

1. The only convertible line . . . install VHF now . . . add UHF later.
2. No couplers needed to add UHF, now or later. Just connect VHF downlead to UHF add-on's terminals.
3. UHF add-on improves VHF reception.
4. Built-in stand-offs keep twinlead in correction position (not required on Ranger-3).
5. Boom is transmission line . . . no wires to corrode or break.
6. All elements are plated (not anodized), making all surfaces conductive (elements on Ranger-3 are pure aluminum).
7. No crimped connections—longer life.
8. Spring-tension, knife-edge contact points mean permanent electrical contact of all elements.

**Mechanical Features:**

1. Dual boom for double strength.
2. No braces or supports required.
3. Snap-out elements, for fastest assembly.
4. U-bolt mounting, for easy assembly and extra ruggedness.
5. Heavy duty 7/16" (not 3/8") elements.
6. Elements reinforced near joints with 6" double tubing.
7. Fewer joints for greater strength.
8. Weatherproof, stripless screw connections.
9. Extra-strong polypropylene insulators.
10. Riveted polypropylene end caps on boom maintain shape under all conditions.
11. U-Ranger has double spot-welded elements for added strength.

## A "Snap" to assemble

There isn't much to say about assembling a Ranger antenna. There just isn't that much to it! Simply:

- Carry it up (one handed) to the mast.
- Snap out the elements.
- Fasten the antenna to the mast with a single U-bolt (two for the ten-element).
- Screw in a stand-off.
- Fasten the downlead to the stripless screws (no cable stripping is required—no extra bracing).
- Now connect the downlead to the set and watch the sharp, crystal-clear pictures on all channels.

To add UHF at any time, fasten the UHF add-on to VHF antenna. Connect the downlead to the UHF antenna instead of the VHF antenna. That's all there is to it!

## What is true log periodic?
## What it is
## What it does

The true log periodic antenna is an outstanding advance over previous antenna designs. It affords reception previously possible only with large commercial antenna installations. The three essential qualities of a good antenna are:

1. Broad, flat bandpass
2. Good match, and
3. High directionality

By comparing these three characteristics, it is easy to understand how this log periodic design outperforms conventional antennas.

### 1. Broad, Flat Bandpass

The bandwidth of a TV channel is approximately 6 megacycles. For optimum reception, an antenna must receive and pass the entire 6-megacyle bandwidth. Loss of bandwidth will result in poor contrast, color smear or even loss of color.

A CONVENTIONAL ANTENNA receives the complete bandwidth of one or two channels, while reception drops off severely on other channels. This causes variations of picture and color quality between stations. (*This is why there are lowband antennas, highband antennas, and single-channel yagis.*)

BLONDER-TONGUE COLOR RANGER true log periodic antennas receive the complete bandwidth of *all* channels. This is because its unique design adds the output of all its elements to produce a constant output at all channels.

### 2. Good Match

Ideally an antenna should match the 300-ohm impedance of the TV set at every channel. Practically, this is impossible. However, for best results an antenna should maintain constant impedance over all channels, because changes in impedance cause changes in picture quality.

Since CONVENTIONAL ANTENNAS have better match at certain channels than at others, they automatically produce variations in picture quality between stations.

The BLONDER-TONGUE COLOR RANGER antennas maintain uniform match on all channels and at a value closely approaching the ideal.

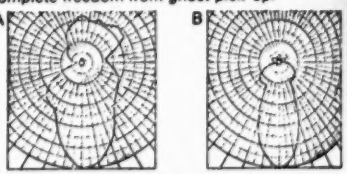
### 3. High Directionality

Antennas can cause ghosts. These occur when a signal is received from more than one direction (e.g. reflected from buildings or hills). While even limited ghosting is annoying on black-and white broadcasts, on color broadcasts ghosts cause smear, loss of color intensity and even complete loss of color.

The two directional patterns below reveal the Color Ranger's superior performance.

The extra lobes of the CONVENTIONAL ANTENNA'S directional pattern (A) show it will receive considerable signal from several directions. This permits both direct and reflected signals to enter the set, causing ghosts.

The absence of lobes on the BLONDER-TONGUE COLOR RANGER (B) proves its almost complete freedom from ghost pick-up.




DON'T FORGET . . . a TV distribution system is only as good as its components. Blonder-Tongue makes a complete line of "top-rated" amplifiers, converters, couplers, and splitters to meet every need.

---

**BLONDER-TONGUE**

*9 Alling Street, Newark, New Jersey 07102*

home TV accessories • closed circuit TV • community TV • UHF converters • master TV

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Distributed by:

To re-order, refer to No. 52

First antenna that delivers uniform, peak performance on all UHF channels...

employs famed Log-Periodic principle used in U.S. Satellite program

# BLONDER-TONGUE GOLDEN DART ALL-CHANNEL UHF ANTENNA

The logarithmic-periodic principle is recognized as today's most modern approach to TV antenna design. The new Blonder-Tongue Dart takes full advantage of the inherent characteristics of the log-periodic design. Eleven elements are employed. The result: The Dart delivers constant high gain, matched impedance and a uniform polar pattern across the full UHF spectrum.

## POLAR PATTERN & 10db GAIN UNIFORM ACROSS ENTIRE UHF SPECTRUM

No matter what UHF channels serve your area – from 14 to 83 – the Dart delivers a sharp, clean pattern on every channel. The Dart maintains an excellent front-to-back ratio (more than 20 db) – equal or superior to a stacked bow-tie over the entire UHF range. The elements are arranged to provide a narrow forward beam for sharpest directivity, minimizing ghosts and other interference. An extremely low VSWR (2:1) prevents other causes of ghosts and smears. Finally, good impedance match on all channels – far superior to bow-ties – assures high uniform gain (±1 db across the entire band; ±½ db within any channel) on all channels.

## FULL BANDWIDTH, FLAT RESPONSE (± ½ db) ON ALL UHF CHANNELS.

Three requisites of good black & white and color reception are maintained. Result: black & white pictures are "live" with a full tonal range of whites, greys, blacks; and color come through with true fidelity.

## COMPLETELY PRE-ASSEMBLED—NOTHING TO SNAP-OUT, NO SCREWS TO TIGHTEN

Take it from the box—mount it—connect your lead, and it's ready to use. Patented stripless screw terminals make connection of twin lead more secure than with other antennas, because the teeth of the phosphor bronze washer grip *both* the insulation and the wire. And wire is fully protected at the point of contact. Polypropylene holders guide the lead-in, keeping the distance between the lead-in and the metal of the antenna uniform at all points to preserve the impedance match. The Dart is the most compact of all UHF antennas – only 17" long. Its low vertical height displacement (2½") makes it easy to piggyback with any VHF antenna. Complete with 2 U-bolts for secure mast mounting.

## RUGGED, UNITIZED WELDED CONSTRUCTION FOR EXCELLENT PERFORMANCE

Welded construction (no rivets, no soldering) means no movable parts that can corrode and impair performance. Other features: sturdy aluminum alloy with long lasting mil-spec iridite finish; heavy polypropylene insulators used instead of usual polystyrene which has a tendency to crack. Another advantage is that the Dart is grounded to the mast. If the mast is grounded, *no lightning arrester is needed!*

## ENGINEERED BY THE COMPANY WITH THE MOST UHF EXPERIENCE

The same know-how employed in designing and producing more than 2 million UHF converters . . . the experience of having worked in every part of the UHF spectrum . . . has gone into making the finest UHF antenna in the field.

The Blonder-Tongue UHF Dart provides peak performance across the full UHF spectrum to match the high performance standards of Blonder-Tongue UHF converters.

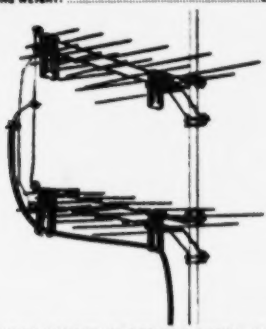
YC-2015
©Dec. 1963

# BLONDER-TONGUE CHANNEL 14 TO 83 TV ANTENNA— GOLDEN DART

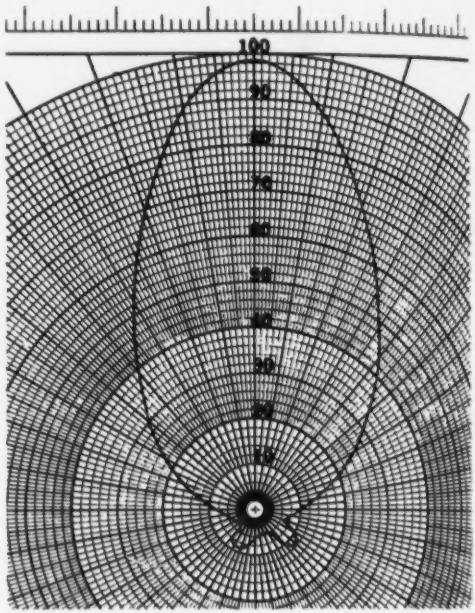
## TECHNICAL SPECIFICATIONS

### TABLE OF SPECIFICATIONS

**FREQUENCY COVERAGE:** ..... 470 mc-890 mc
(Frequency coverage actually extends slightly below and above the above limits).
**INPUT MATCH:** ..... 2:1 or better over the entire UHF band.
**GAIN OVER TUNED DIPOLE:** ..... ( 9.2 db at 490 mc)
10.0 db average ..... (11.0 db at 700 mc)
(10.5 db at 880 mc)
**FRONT-TO-BACK RATIO:** ..... 20 db minimum (typical 24.0 db)
**BEAM WIDTH HORIZONTAL:** ..... (50° at 490 mc)
(half power points) ..... (53.5° at 700 mc)
(41.0° at 880 mc)
**POLARIZATION:** ..... Horizontal
**NUMBER OF ELEMENTS:** ..... Eleven
**MOUNTING:** ..... Mast mounting (1"-2½" mast)
Mounts with two clamps (supplied).
**TRANSMISSION LINE:** ..... 300 ohms balanced
(twinlead or tubular.
**CONSTRUCTION:** ..... steel with mil spec
zinc plate iridite finish (silver color)
**SIZE (HWL):** ..... 2½" x 131⅞" x 17"
**ANTENNA WT.:** ..... 1 lb.
**SHIPPING WEIGHT:** ..... 2 lbs.



**STACKED GOLDEN DARTS FOR EXTRA GAIN**
Two Golden Darts may be stacked easily for extra gain (3 db) and better impedance match (3:1). Order model 351[9] stacking bars.




### RELATED BLONDER-TONGUE EQUIPMENT

Blonder-Tongue manufactures the world's only complete line of UHF products. All-channel UHF converters include the model BTC-99S for prime signal areas and the BTU-2T with 8 db gain. To improve reception in weak signal areas, where older TV sets or a non-amplified converter is used, the U-BOOST all-channel indoor UHF booster is the solution. For fringe areas, the mast-mounted ULTRABOOSTER is recommended.

engineered and manufactured by
BLONDER-TONGUE
9 Alling St., Newark, 2 N.J.
Canadian Div.: Benco Television Assoc., Ltd., Toronto, Ont.
*home TV accessories • closed circuit TV • community TV • UHF converters • master TV*

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# BLONDER-TONGUE UHF ANTENNAS
# GOLDEN ARROW INDOOR/GOLDEN DART OUTDOOR
# TECHNICAL SPECIFICATIONS

## FEATURES:
### GOLDEN DART AND GOLDEN ARROW

**PEAK PERFORMANCE ON ALL UHF CHANNELS** – delivers sharp, clear pictures on every channel 14 to 83.

**PERIODIC DESIGN**–Dart uses 11 working elements (the Arrow 10 working elements) to provide constant high gain and matched impedance.

**EXCELLENT FOR COLOR AND BLACK & WHITE TV** – Full bandwidth, flat response from channel 14 to 83.

**MINIMIZES GHOSTS AND OTHER INTERFERENCE** – Excellent front-to-back ratio, sharp directivity.

### GOLDEN DART

**COMPLETELY PRE-ASSEMBLED** — Nothing to snap out — no screws to tighten — just take it from the box and it's ready to use. Patented stainless steel stripless screw terminals make connection of twin-lead a snap.

**MOST COMPACT OF ALL UHF ANTENNAS** — Only 17 inches long. Low vertical height displacement makes it easy to piggy-back with any VHF antenna. (Complete with two U-bolts for secure mast-mounting.)

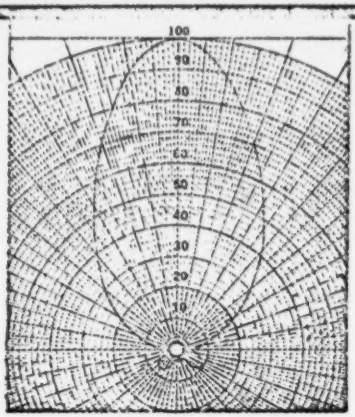
**RUGGED, UNITIZED WELDED CONSTRUCTION**–No rivets, no soldering–mean no moveable joints that can corrode and impair performance.

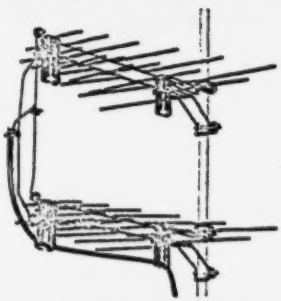
### GOLDEN ARROW

**RUGGED CONSTRUCTION** – Welded construction means durability. Complete with 300-ohm twin-lead with spade lugs for 30-second installation. Connection is far more secure than any other antenna. Won't pull apart. Skid-proof rubber legs.

## SPECIFICATIONS
### GOLDEN DART AND GOLDEN ARROW

**FREQUENCY COVERAGE:** .....465 mc-890 mc
**VSWR:** .....3 or better over entire UHF band
**FRONT-TO-BACK RATIO:** .....(Arrow) 20 db min.
(Dart) 20 db min. (typical 30.0 db)
**HALF POWER BEAM WIDTH (horizontal):** .....Approx. 50°
**POLARIZATION:** .....Horizontal
**NUMBER OF ELEMENTS:** .....(Arrow) 10 (Dart) 11
**MOUNTING:** .....(Arrow) Mounts on stand supplied
(Dart) Mast mounting (1-2½" mast); two clamps (supplied)
**TRANSMISSION LINE:** .....(Arrow) 300-ohm balanced. (4' twinlead supplied)
(Dart) 300-ohm balanced twinlead
**CONSTRUCTION:** .....(Arrow) steel wire with brass, plate lacquer dip
(Dart) steel with mil spec zinc plate iridite finish (gold color)
**SHIPPING WEIGHT:** .....(Arrow) 1½ lbs. (Dart) 2 lbs.
**SIZE (HWL):** .....(Arrow) 12"x6"x8½"
(Dart) 17" x 14" x 3¾"



**STACKED GOLDEN DARTS FOR EXTRA GAIN**
Two Golden Darts may be stacked easily for extra gain (3 db) and better impedance match (VSWR 2.0). Order model 3519 stacking bars.

### RELATED EQUIPMENT

Blonder-Tongue manufactures the world's most complete line of UHF products including a variety of UHF converters for all reception areas. To improve snowy pictures in difficult reception areas, use the mast-mounted Able-U2 UHF amplifier. To combine or split antennas or transmission lines, use the UHF-2 coupler.

The A-107 coupler can be used to combine or split UHF & VHF signals. The new UV-2 is the world's first channel 2 to 83 two-set coupler.

**BLONDER-TONGUE**
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Export: Morhan Exporting Corp. N. Y. 3, N. Y. Cable: Morhanex

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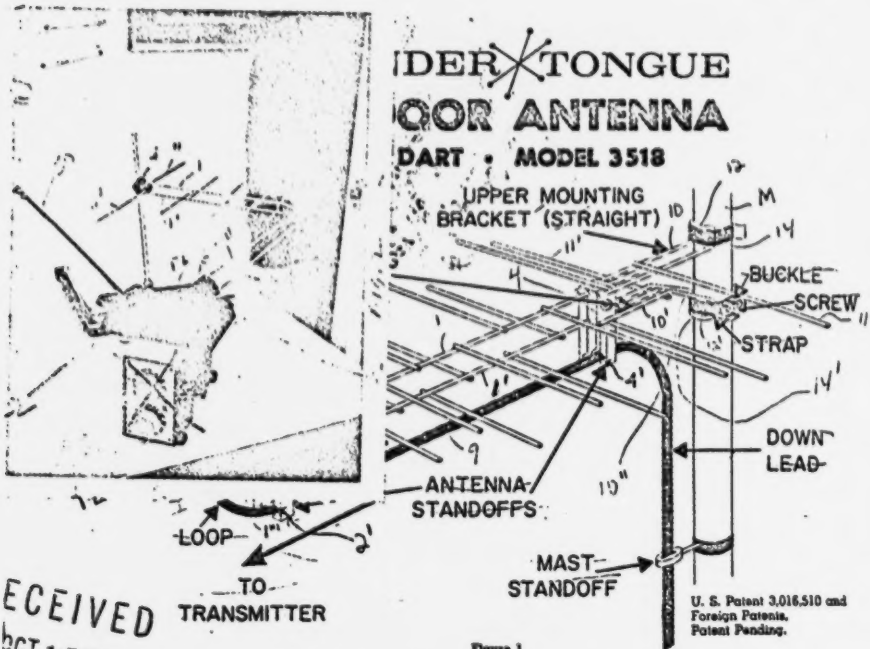


Figure 1

ECEIVED
OCT 15 1963
SANDERS
OFFICE SQUARE, BOSTON
RECEIVED
OCT 7 1963
SANDERS

**THE DART IS A QUALITY ANTENNA THAT EMPLOYS THE LATEST DEVELOPMENTS IN THE ANTENNA FIELD**

*Among Its Features*

- **All joints welded for long life**
- **Front-to-back ratio over 20 db**
- **Completely pre-assembled**
- **Excellent for color TV**
- **Works with all-channel sets, UHF boosters and UHF converters**
- **Good match and gain over the full UHF band**

Fig 1

## INSTALLATION INSTRUCTIONS

1. Remove the antenna from the carton.
2. Remove the plastic bag. It contains: (2) stainless steel mounting straps.
3. Place antenna on the pole (as shown in Figure 1). Make sure that the straight mounting bracket is on top. Pull the mounting strap around this mounting bracket and the mast. Then, thread the mounting strap through the buckle (from inside out) and tighten the screw until the unit is secured.
4. Now secure the lower mounting bracket in the same manner. (Bend the loose ends of the straps, around and behind the antenna).
5. Down lead 300Ω connection.
   - A. It is recommended you use low loss foam twinlead. If you use flat twinlead, cut slit 1¼" to 1½" as shown in fig. 2. Slip each side of the twinlead under the sawtooth washers and then tighten the screws so that these washers pierce the twinlead, making contact with the wires inside. Be careful not to strip the threads of the terminal screws by turning them too hard. To attach UHF tubular or encapsulated twinlead, reduce the thickness of the cable by trimming off with a knife about 1/16" from each wide surface.
   - B. If a low loss coaxial downlead is desired, a balun such as Blonder-Tongue CMB-92U can be used. RG11/U foam cable is recommended.
   - C. Form a loop as shown in Figure 1. Slip cable into antenna stand offs, allow no slack in cable. Dress cable as shown, and use additional UHF standoffs alongside the mast. Make sure that the cable will not touch any metal parts of the antenna or the mast.

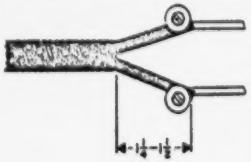


Figure 2

6. After connecting your antenna properly, orient your antenna towards the transmitter as shown in figure 1 for best picture reception.

LOG-PERIODIC UHF-FM ANTENNA

# COLOR RANGER-10

# INSTRUCTIONS

Your new Color Ranger-10 is an advanced, ten-element log-periodic antenna, designed for optimum reception of VHF and FM. It is especially effective for color reception, featuring high, uniform gain and a precisely-shaped directional pattern, which aids in eliminating ghosts. The Color Ranger's mechanical and electrical design incorporate the very latest developments in antenna engineering. The Ranger-10 utilizes twin-boom construction, with its superior electrical characteristics and mechanical rigidity. Self-locking, snap-out elements ensure correct positioning, and are reinforced at critical points. A chromateiridite finish provides excellent protection against the elements, assuring long, trouble-free service.

The antenna has provisions for UHF addition at any time. By simply turning four nuts, the Blonder-Tongue U-Ranger antenna, designed to function as an integral part of the Ranger 10, can be added for UHF reception. No antenna couplers or separate leads to the set are required.

All Blonder-Tongue antennas are built to the very highest standards. Every unit undergoes a comprehensive inspection before receiving the Blonder-Tongue insignia. In this way, we strive to maintain the quality and reliability with which the Blonder-Tongue name has been synonomous for over fifteen years.

## FOR THE MAN IN A HURRY

Don't be surprised at the length of these instructions. Because this antenna is a quality design, manufactured with great care, it is only natural that we wish to assure it will perform to its maximum capabilities. For this reason, we have included several paragraphs of installation techniques, to aid you in setting up your system.

Our technical writers and engineers have spent considerable time preparing these instructions for your guidance. To attain the best results, please read this entire booklet carefully, with the antenna in front of you, BEFORE proceeding with installation. It will be time profitably spent.

## INSTALLATION TIPS

Following these installation tips will aid you in making an installation of professional quality. Should you encounter unusual problems or special situations, consult your dealer. Authorized Blonder-Tongue dealers have a wealth of invaluable practical television experience. Yours will be only too glad to give you guidance in installing (or enlarging) your Blonder-Tongue TV system.

### Location

Particular attention should be paid to the antenna location, as it may make the difference between a poor and an excellent picture.

1. Wherever possible, the antenna should be mounted above all local obstacles, such as buildings or nearby trees. Use the height of your neighbors' antennas as a guide.

   In addition, try to avoid having large structures of the same height behind the antenna, since they may cause ghosts.

2. The antenna should be mounted away from power lines. Keep in mind that power lines can blow in the wind, and sag when carrying ice or snow. Mount the antenna where tree branches will not blow into it.

3. Some codes require that the antenna mast be grounded. Your dealer can supply the necessary parts to accomplish this.

4. Keep the antenna away from chimneys of buildings where coal or oil is burned. These fuels sometimes deposit carbon on antennas, resulting in poorer performance.

5. Support the antenna mast at a minimum of two points. As a rule of thumb, at least 1/4 of the total mast length should lie between the two supporting points. Masts over 10-15 feet may require guy lines (ask your dealer).

6. Be sure the mast mounting is firmly secured to a firm support, such as a masonry wall, a house structural member, etc. A wide variety of masts and mountings are available from your Blonder-Tongue dealer, who will be glad to recommend the type best suited to your



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own particular requirements.

7. Be sure to use stand-offs, as recommended in the installation section. If the cable flaps excessively, it is possible that the wires within the cable may break. In an apartment building, the simplest way to run a cable is next to the line of windows. Since other cables may also be mounted in this manner, try to place stand-offs so that your cable is a minimum of six inches away from any others.

8. If severe problems are encountered and no other solution works, try relocating the antenna, or changing its height.

### Cable

A word about cable is in order here. To ensure maximum system performance, it is important to use high-quality cable between the antenna and set, since inferior cable may result in considerable signal deterioration, especially in wet weather. This becomes even more important with UHF systems, or in systems where UHF will be added later, since losses are always greater at UHF frequencies.

High-quality, professional UHF/VHF foam-filled cable, such as the type shown in Figure 3, provides the lowest loss and greatest durability in these applications.

After deciding upon the location of your antenna and set(s), estimate the amount of cable you will need. Always buy at least 10% more than this length, as a safety factor, especially if you are planning to add a U-Ranger to your antenna. Remember that it is always better to cut off a small extra length of cable than to be forced to splice the cable, especially at the rooftop, or some other inconvenient location. Below are some precautions to be followed with cable:

1. Wherever possible, keep cable away from metal surfaces, which can cause signal losses, and sometimes ghosts.

2. Never staple cables to the outside of buildings, use stand-offs every 4 to 5 feet apart. Put a twist in the wire every 3 to 5 feet, for reduced noise pickup.

3. Keep the cable reasonably taut, to prevent damage from collision with the building or other objects.

4. In areas near broadcast transmitters, use the shortest possible horizontal cable runs. Where noise pickup is a problem, use the shortest possible vertical runs.

5. For indoor runs, the use of plastic cable clamps is recommended.

6. Be sure the cable is not squeezed by metal casement window-frames.

7. The cable may be brought into the house by drilling a hole and inserting a plastic form designed for the purpose, or by filling the hole with putty.

## INSTALLATION

To perform the installation, you will need a pair of gas pliers (or wrench) and a knife or other tool, to taper and strip the twin-lead. In addition, you will need one or more mast-mounted stand-offs (if your antenna mast is longer than 3 feet, and enough additional stand-offs to keep the cable away from the building walls.

First, check the hardware bag for the following items (see Figure 1):

1 U-bolt
1 flat metal plate
1 U-bolt clamp
2 bolts
2 saw-tooth washers
2 screw-in (boom) stand-offs
2 nuts
2 wing-nuts

Now proceed as follows:

1. Screw the boom stand-off into one of the booms (see note below), as shown in inset A of figure 2. Be sure that it goes through both sides of the boom, but tighten it only so far as the illustration shows.

NOTE

Both antenna booms are identical. Whichever one you mount the standoff on becomes the bottom (lower) one.

2. If you are planning to use a Blonder-Tongue U-Ranger (see 'ACCESSORIES,' below) in conjunction with the Ranger 10, proceed to the beginning of the U-Ranger instructions. If you are NOT using a U-Ranger, place one of the bolts supplied in each of the holes on the front of the antenna (see inset B, figure 2).

3. Place a saw-tooth washer and wing-nut on each of the bolts, as shown in inset B. Turn the wing-nuts a few times, to keep them on the bolts. They will be tightened later.

4. Take the antenna to its mounting site. All following steps will be performed there. Be sure that the mast is securely fastened to the roof, wall, etc.

NOTE

If the mast is too high or inconveniently placed to reach easily, the antenna, mast stand-off, cable, etc. should be installed as indicated in steps 6 through 10 below before the mast is placed in its final location.

If your mast is longer than 3 feet, you will need to purchase at least one mast-mounted stand-off (see Figure 1). Place the first mast-mounted stand-off as shown in Figure 2, and the other standoffs every 4 to 5 feet apart thereafter.

5. Partially swing out all elements (tubes) near the mounting bracket of the antenna (the black plastic piece with the holes in it), so that the elements will not be prevented from opening by the mast. Using the U-bolt, metal plate, U-bolt clamp and 2 nuts, mount the antenna on the mast, as shown in Figure 2. Be sure that the raised areas around the holes of the metal plate are pointed towards the black plastic block, and that the antenna booms are horizontal. Tighten the nuts FIRMLY.

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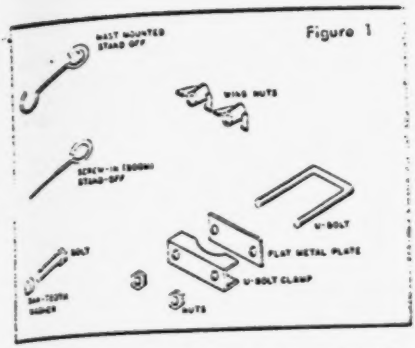

Figure 1

Orient the antenna (see Figure 2) in the general direction of the stations. Use the position of your neighbors' antennas as a guide.

6. Make a 2-1/2 to 3-inch slit in the twin-lead. If you are using foam-filled cable, taper the twin-lead as shown in Figure 3 – there is no need to strip the cable.

7. Run the slit end of the cable through the mast-mounted stand-off(s) and the boom stand-offs, leaving enough slack for connection to the antenna terminals.

NOTE

Some stand-offs will not readily accommodate encapsulated cable. If the stand-off opening proves too small, it may be enlarged with a rasp, or you may bend the metal portion of the stand-off, as shown in figure 4, before inserting the cable.

8. Place one side of the slit cable under one of the saw-tooth washers, as shown in inset B of Figure 2.

NOTE

If a U-Ranger is used, do NOT connect the cable to the front of your antenna – connect it to the front of the U-Ranger, as shown in Figure C of the U-Ranger instructions.

Tighten the wing-nut securely, so that the washer makes contact with the wire inside. Excessive pressure is not required. Do the same with the other side of the cable and the other washer and wing-nut.

9. Check to see that the cable is run as shown in Figure 2. There must be no sharp bends in the cable. Wind electrician's tape in a 'figure-8' pattern over all stand-offs (see Figure 2), to prevent cable slippage.

10. Now, grasping the antenna elements near their pivot points, swing each element out until it clicks. Inset D of Figure 2 shows the correct locked position. Test each element by moving it gently from side to side, to ensure that it is locked.

11. Now run the cable from the antenna to your set, keeping in mind the precautions mentioned in the previous section.

12. Observe the picture on your television set. If there are ghosts present, try reorienting the antenna. Check all channels. In some cases, a compromise between the ideal locations for all channels must be used.

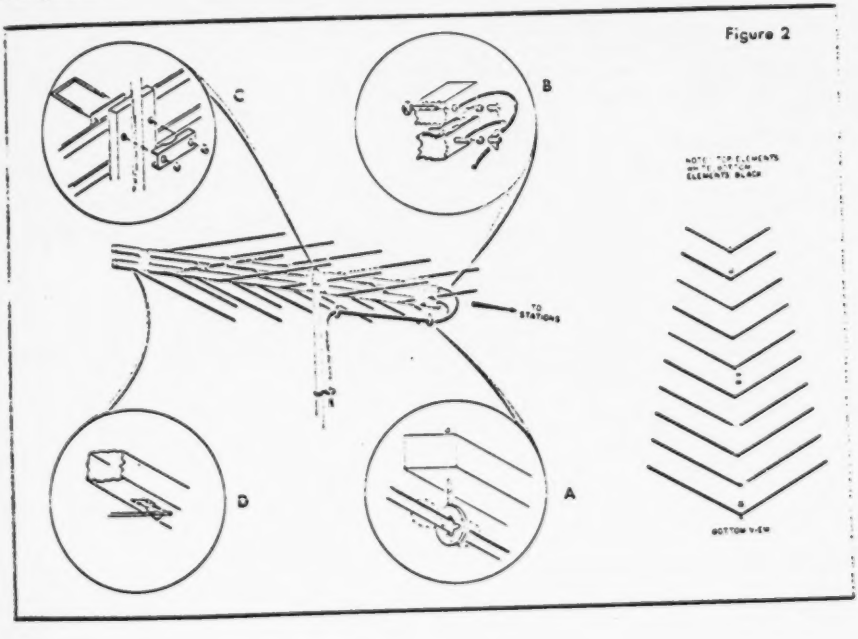

Figure 2

ST20

Special Problems

1. Ghosts – This problem can usually be reduced or eliminated by reorienting the antenna. Try turning the antenna to a variety of positions as you or a friend watch the TV screen. The best position may not necessarily be when the antenna is pointed directly at the station(s). Remember to check all stations as you shift the antenna, since a compromise may be necessary to achieve the best picture on all channels. If a satisfactory compromise cannot be achieved, you may require an antenna rotator.

   Two other possible causes of ghosts are cables too close to other cables, and too much metal close to the cable. The first can be cured by keeping your cable at least six inches away from all other TV cables. If the cable must be run near large metal surfaces, try using longer stand-offs. If this fails, it may be necessary to use coaxial cable. If you are thinking about purchasing a rotator or coaxial cable, see your dealer, explaining the difficulty. He may be able to suggest a simpler, less costly solution.

2. No Picture, Snow, or Poor Contrast – Too little signal is the cause here. Check all connections, and check the cable for shorts or breaks. If this happens in wet weather only, replace your cable with foam-filled twin-lead (see 'Cable,' above).

   If you are in a fringe area, you may wish to install a signal amplifier. See your dealer about a Blonder-Tongue unit to meet your requirements.

3. Fading Picture – This may be caused by a branch hitting the antenna, or by the wind shifting the direction of the antenna. Clear all obstacles away from the antenna, and provide a sturdier mast mounting, if necessary.

4. Interference – Interference may come from a variety of sources. A line filter for your TV set, a high-pass filter at the antenna input of your TV set, or coaxial cable are among the possible solutions. See your dealer for further information.

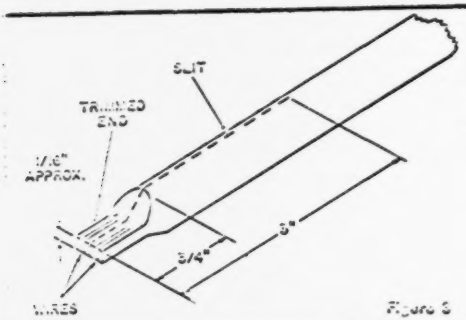


Figure 3

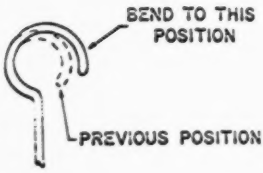


Figure 4

## ACCESSORIES

Blonder-Tongue manufactures a complete line of color-approved home distribution equipment, including antennas, signal amplifiers, matching transformers for TV and FM, and UHF converters. Below is a partial list.

| | |
|---|---|
| U-Ranger | UHF add-on antenna for use with Blonder-Tongue Color Ranger antennas. |
| U/Vamp-2 | mast-mounted two-transistor VHF/UHF signal amplifier. |
| Vamp-2 | mast-mounted two-transistor VHF signal amplifier. |
| V/U Am-2 | indoor, two-transistor VHF/UHF signal amplifier. |
| MT-300 | VHF/UHF/FM transformer for matching antenna to coaxial download, and coax to set. |
| Coblumatch U/V | indoor VHF/UHF/FM transformer for matching coax to set input. |
| TF-301 U/V | indoor, flush-mounted UHF/VHF/FM feed-through plate. |
| A-102 U/V | VHF/UHF/FM two-set coupler. |
| A-104 U/V | VHF/UHF/FM four-set coupler. |
| A-107 | VHF/UHF coupler-splitter. |
| UTA-11A | transistor UHF converter for weak-signal areas. |
| UTA-99A | transistor UHF converter for strong- and medium-strength signals. |
| UTD-44 | tunnel-diode, cordless UHF converter for strong-signal areas. |

See your dealer for further information on these products, as well as specific recommendations to meet the particular requirements of your own installation.

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BLONDER-TONGUE LABORATORIES, INC./NEWARK, N.J.

# LOG-PERIODIC UHF ANTENNA

# U-RANGER

The U-Ranger is a wide-band log-periodic UHF antenna, designed to attach directly to Blonder-Tongue Color Ranger antennas. This antenna, which operates without couplers of any sort, extends the capabilities of the Color Ranger into the UHF band. By mounting the U-Ranger on a Color Ranger antenna, and switching the cable from the Color Ranger to the U-Ranger terminals, both UHF and VHF signals will be fed to your set(s) on a single cable.

All Blonder-Tongue antennas are built to the very highest standards. Every unit undergoes a comprehensive inspection before receiving the Blonder-Tongue insignia. In this way, we strive to maintain the quality and reliability with which the Blonder-Tongue name has been synonomous for over fifteen years.

## IMPORTANT

Since the U-Ranger is designed to be used with Blonder-Tongue VHF or FM antennas, these instructions are not meant to be used alone. If you are assembling both antennas at the same time, read the precautions and installation tips for the VHF or FM antenna, and begin the installation procedure contained in its manual. These instructions will tell you at what point to begin U-Ranger assembly. If your VHF or FM antenna is already mounted on the mast, proceed with the instructions below.

In order to add UHF to your Blonder-Tongue VHF or FM antenna, you must assemble the U-Ranger. First, check the hardware bag for the following items (see Figure A):

- 2 plastic brackets (A and B)
- 1 bolt
- 1 nut
- 2 wing bolts
- 2 small saw-tooth washers
- 1 metal bracket

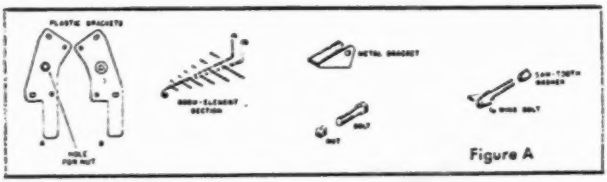


Figure A

Now proceed as follows:

1. Join the two boom-element sections (Figure A), which are identical, as shown in Figure B. Be sure to place the nut in bracket A, whose hole is shaped to receive the nut. Tighten the bolt securely, using a screwdriver or coin.

2. After placing one of the saw-tooth washers (NOT the ones that come with the VHF or FM antenna) on each of the wing-bolts, thread a bolt into each of the two holes on the front of the antenna, as shown in Figure B. Turn them only a few times, to keep them on. They will be tightened later.

### NOTE

The two bolts face in opposite directions, as shown.

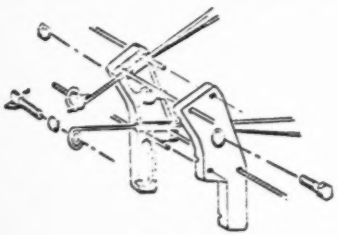


Figure B

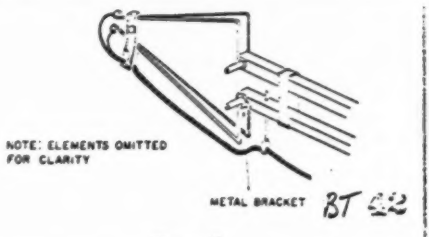


Figure C

Figure D

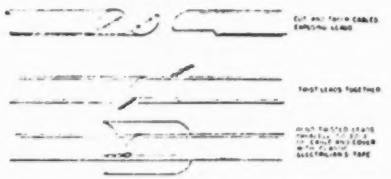
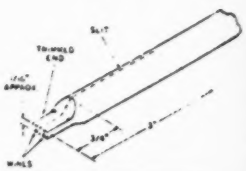


Figure E




IF YOU ARE ASSEMBLING THE VHF OR FM ANTENNA AT THE SAME TIME AS THE U-RANGER, PROCEED AS DESCRIBED IN STEPS 3 AND 4 BELOW. IF YOUR VHF OR FM ANTENNA IS ALREADY INSTALLED, SKIP TO STEP 3a, DISREGARDING STEPS 3 AND 4 BELOW.

3. After spreading the front elements of the VHF or FM antenna, fasten the U-Ranger to it, using two of the bolts and wing-nuts supplied with the VHF or FM antenna, as shown in Figure C. The metal (anti-rotation) bracket goes on the LOWER boom, over the outside of the lower UHF boom-element.

NOTE

Do NOT use a pair of saw-tooth washers supplied with the VHF or FM antenna when attaching the U-Ranger to it.

4. Proceed to step 4 of the instructions for the VHF or FM antenna, disregarding steps 2 and 3 therein.

IF YOUR FM OR VHF ANTENNA IS ALREADY INSTALLED, PROCEED AS FOLLOWS:

3a. Loosen and remove the two wing-nuts which secure the cable to the antenna. Remove and discard the two saw-tooth washers.

4a. Using the two bolts remaining on the antenna and the two wingnuts just removed, fasten the U-Ranger to the VHF or FM antenna, as shown in Figure C. The bracket goes on the LOWER boom, over the outside of the lower UHF boom-element.

5a. Extend the cable so that it reaches the terminals of the U-Ranger. You may have enough slack in the cable to do this readily; otherwise you may either replace the entire cable (probably the most practical method for short runs), using a high-quality foam-filled cable, or splice in a length of cable, as shown in Figure D.

6a. Connect one conductor to each of the two stripless terminals as follows. If you are using foam-filled cable, taper and slit the cable as shown in Figure E, (if you are not using the ends removed from the VHF or FM antenna terminals) and insert one side under each of the saw-tooth washers. With flat cable, make a 3" slit in the cable and proceed as above. Tighten the wing-bolt securely (excessive pressure is not required).

## ACCESSORIES

Blonder-Tongue manufactures a complete line of color-approved home distribution equipment, including antennas, signal amplifiers, matching transformers for TV and FM, and UHF converters. Below is a partial list.

| | |
|---|---|
| U/Vamp-2 | mast-mounted two-transistor VHF/UHF signal amplifier. |
| Vamp-2 | mast-mounted two-transistor VHF signal amplifier. |
| V/U All-2 | indoor, two-transistor VHF/UHF signal amplifier. |
| MT-283 | VHF/UHF/FM transformer for matching antenna to coaxial downlead, and coax to set. |
| Cablematch U/V | indoor VHF/UHF/FM transformer for matching coax to set input. |
| TF-331 U/V | indoor, flush-mounted UHF/VHF/FM feed-through plate. |
| A-102 U/V | VHF/UHF/FM two-set coupler. |
| A-104 U/V | VHF/UHF/FM four-set coupler. |
| A-107 | VHF/UHF coupler-splitter. |
| BTX-11A | transistor UHF converter for weak-signal areas. |
| BTX-99A | transistor UHF converter for strong- and medium- strength signals. |
| BTD-44 | tunnel-diode, cordless UHF converter for strong-signal areas. |

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See your dealer for further information on these products, as well as specific recommendations to meet the particular requirements of your own installation.

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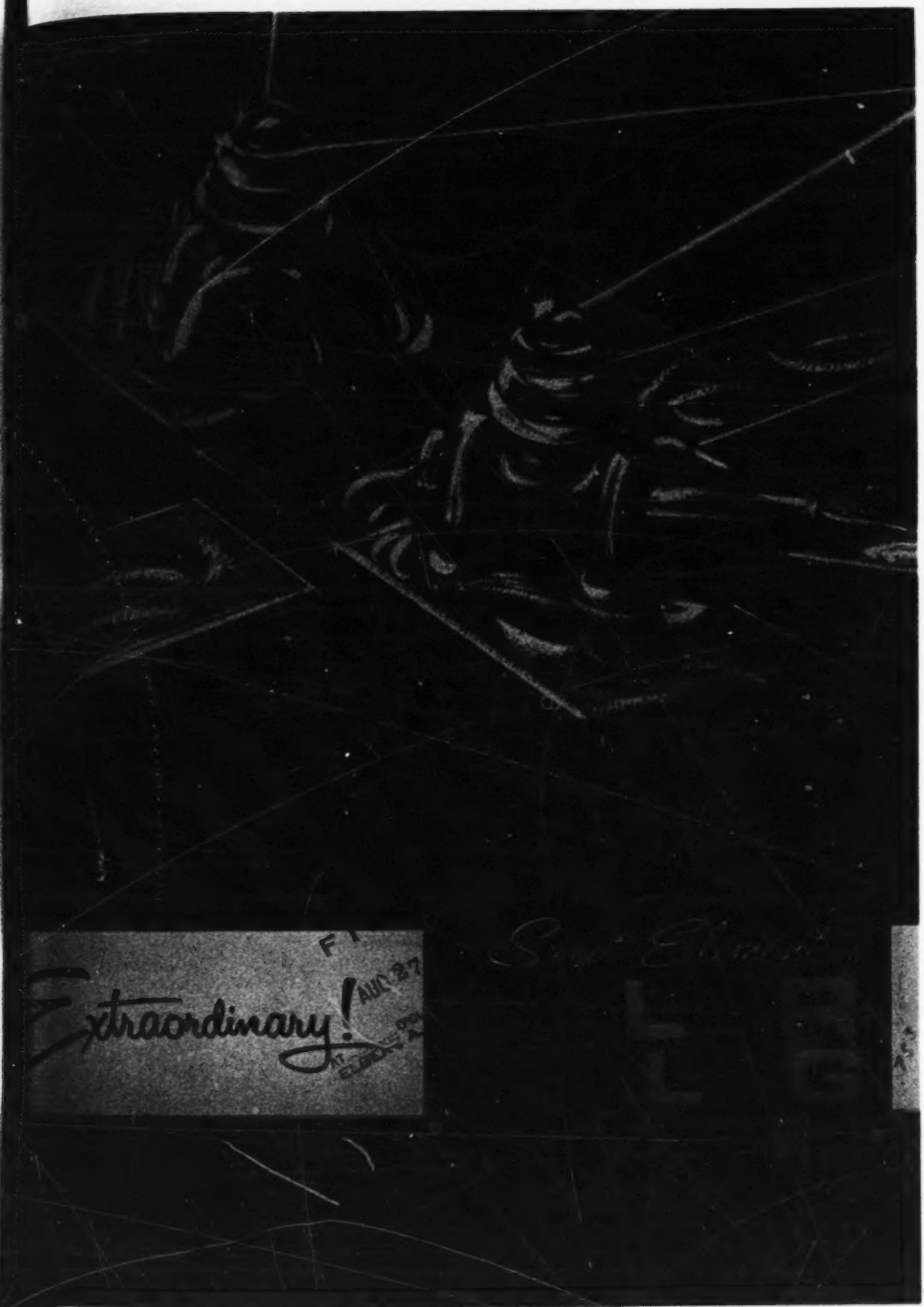

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MODEL VI-10
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snap-in triple thick elements. An added exclusive feature is the snug fitted aluminum cup for extra
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back-up bracket adds triple strength to the riveted assembly of 1" heavy duty square boom to the alum
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the heavy duty square boom, because FINCO developed the back-up bracket to eliminate boom
positioned cleats assure sag-free positive direction of the antenna, and because FINCO brackets are rus
FINCO'S boom-mast bracket is the finest and most trouble-free available! **4 FINCO'S EXCLUSIVE TRI**
**ELEMENTS.** Not only does the new FINCO VE-LOG feature the finest extra heavy walled aluminum tubing fo
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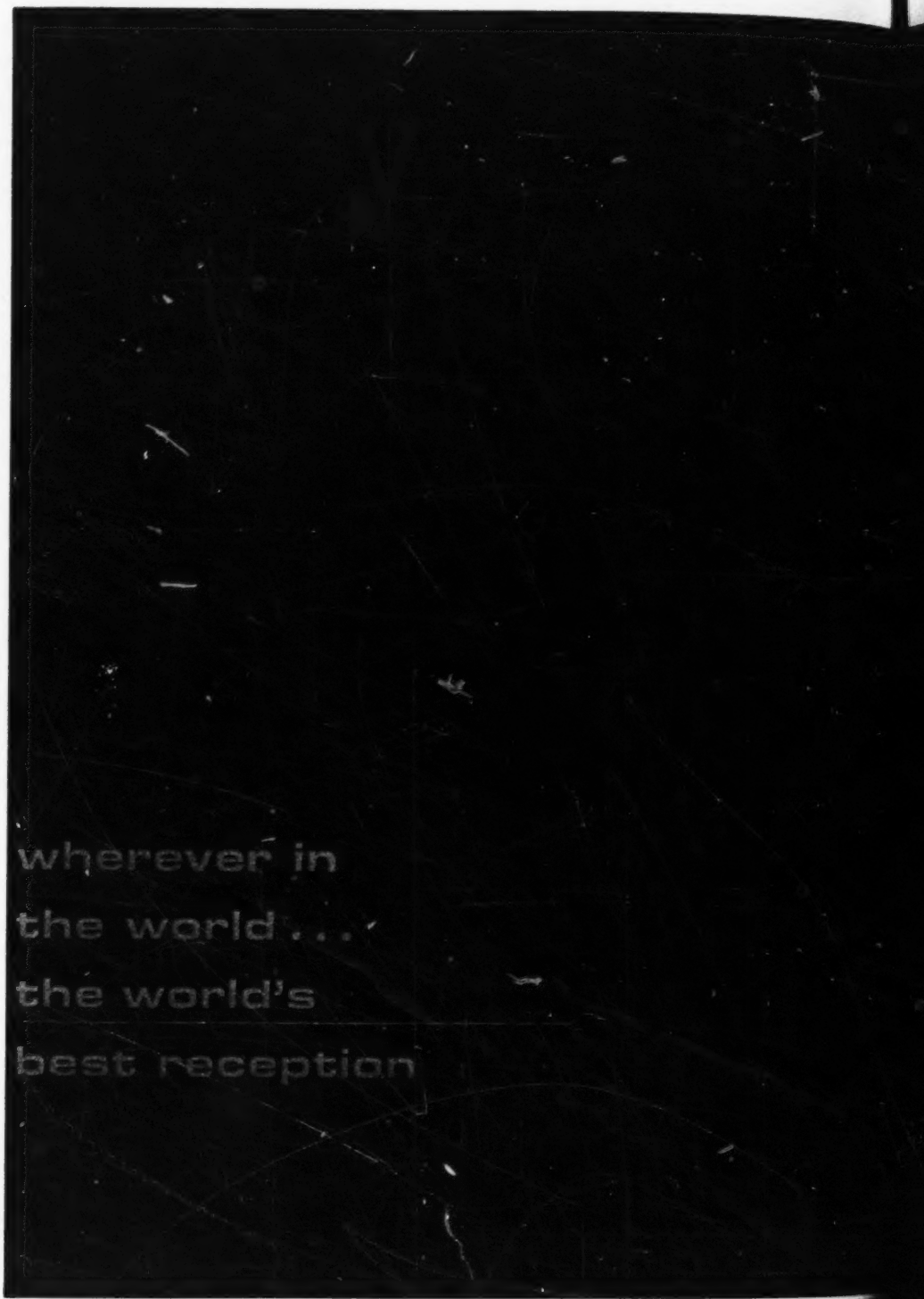
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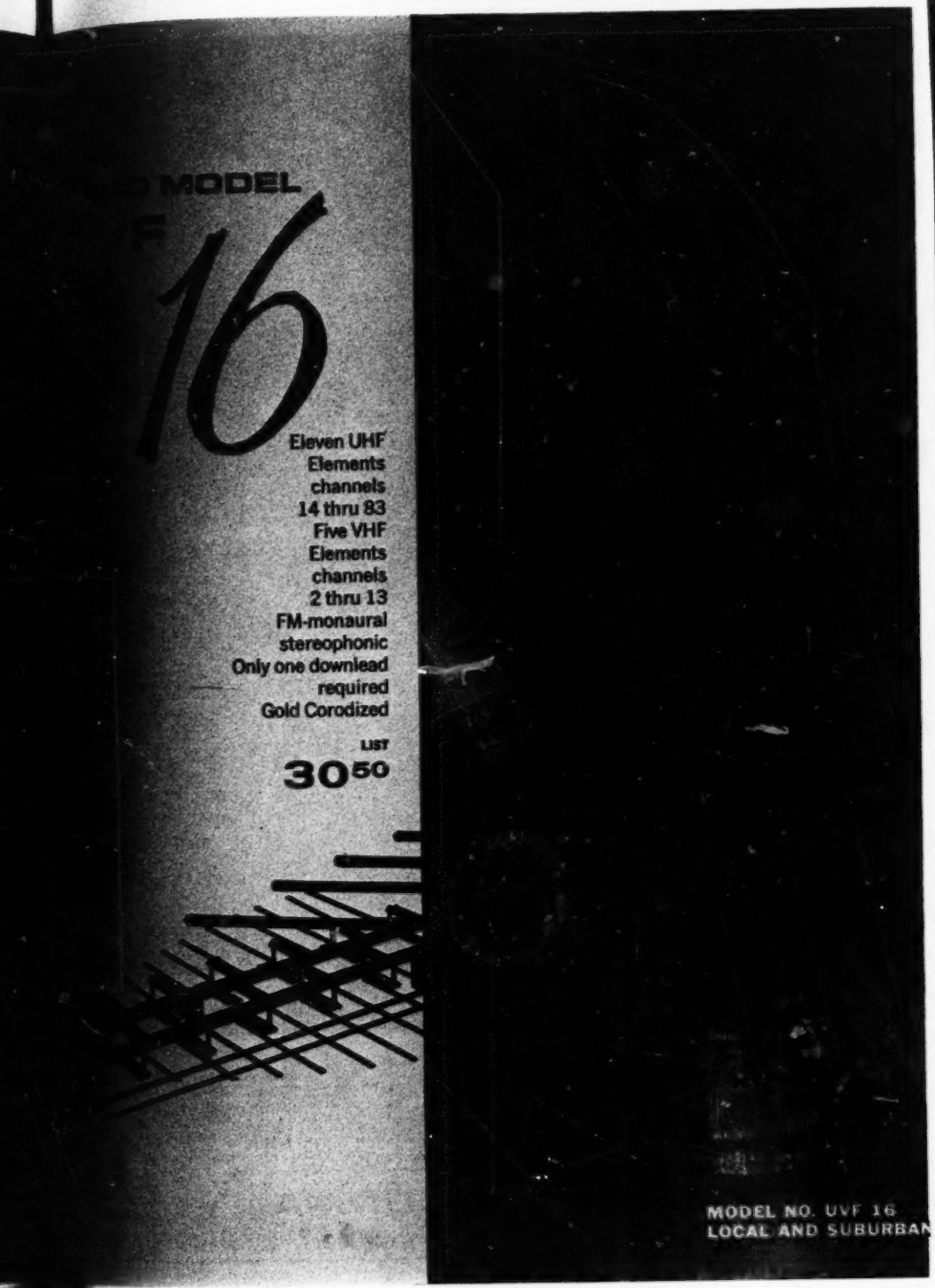
MODEL
16
Eleven UHF
Elements
channels
14 thru 83
Five VHF
Elements
channels
2 thru 13
FM-monaural
stereophonic
Only one downlead
required
Gold Corodized
LIST
30.50
MODEL NO. UVF 16
LOCAL AND SUBURBAN

METROPOLITAN AREA

FINCO MODEL
UVF 10

Seven UHF Elements channels 14 thru 83
Three VHF Elements channels 2 thru 13
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Only one downlead required
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LIST
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UHF-VHF-FM ANTENNAS

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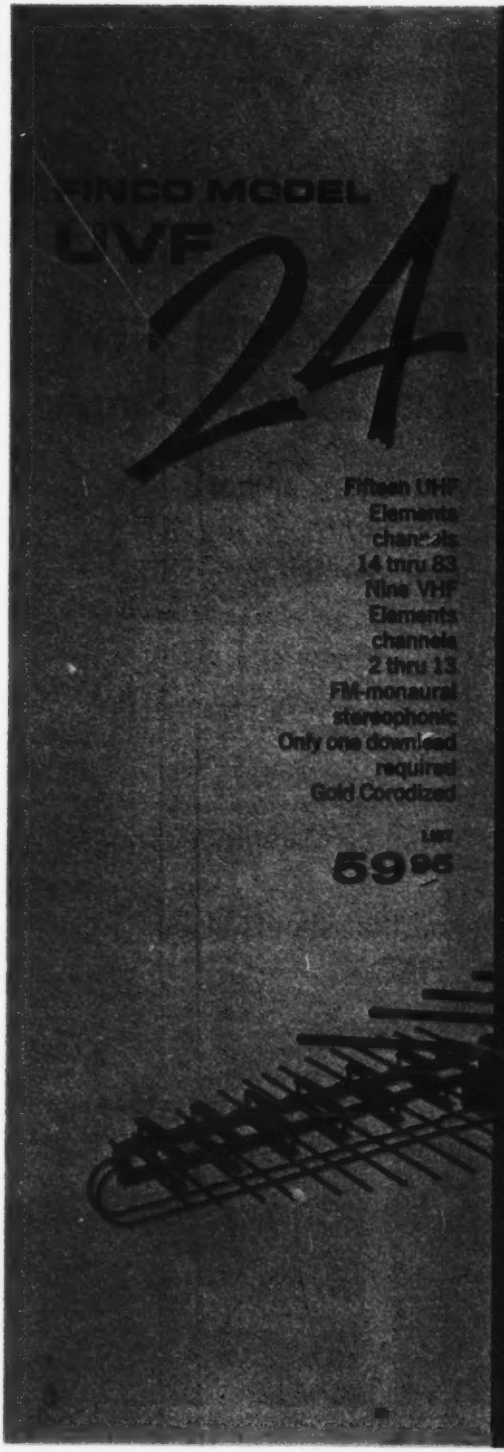
PINCO MODEL
UVF
24
Fifteen UHF
Elements
channels
14 thru 83
Nine VHF
Elements
channels
2 thru 13
FM-monaural
stereophonic
Only one downlead
required
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MODEL
18
Eleven UHF
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Seven VHF
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1. UHF SECTION. Revolutionary New Step-staggered, Log Configurated, Serrated UHF Frontal Design. Rugged perfected performance.

2. METAL (HEAVY ALUMINUM) REINFORCED INSULATOR INSERT CUP AND HEAVY DUTY RIVET! Finco's new large heavy duty polystyrene insulators now are reinforced by a unique heavy aluminum shield to give quadruple strength for supporting positive positioned snap-in triple thick elements. An added exclusive feature is the snug fitted aluminum cup for extra support to the oversize aluminum rivet—truly a life-time assembly! 3. BACK-UP BRACKET AND SQUARE BOOM. FINCO'S exclusive aluminum back-up bracket adds triple strength to the riveted assembly of 1" heavy duty square boom to the aluminum shielded polystyrene form fit element bracket, making the boom non-crushable! 4. FINCO'S EXCLUSIVE TRIPLE THICK SLEEVED ELEMENTS. Not only does the new FINCO VE-LOG feature the finest extra heavy walled aluminum tubing for its elements, but to assure mechanical design superior to ordinary antennas, a triple thick sleeve assembly is used for assurance plus strength to combat destructive high winds and wet snows. First a die stamped bracket with triple strength aluminum rivet, then a long oversized outside sleeve shell plus the aluminum element itself. FINCO invites competitive comparison! 5. LOCK TITE NO-TILT SADDLE BRACKET. Because FINCO pioneered the heavy duty square boom, because FINCO developed the back-up bracket to eliminate boom crushing, because positioned cleats assure zag-free positive direction of the antenna, and because FINCO brackets are rustproofed, therefore, FINCO'S boom-mast bracket is the finest and most trouble-free available! 6. FINCO'S EXCLUSIVE DOUBLE CONTACT TO DRIVE LINE. Never before has there been designed such a positive, vibration-free, non-corrosive contact for perfect drive line support and electrical continuity. An ingenious all aluminum die stamped double clip with preformed rivet cup and spring tension base for permanent trouble-free contact completion to be found on no other antenna! 7. CONTINUOUS ONE PIECE DRIVE LINE AND EXCLUSIVE AIR INSULATED HIGH IMPACT POLYSTYRENE CROSS-OVER SPACER. No more jointed drive lines as commonly used on other antennas! FINCO proudly presents the first continuous one-piece heat treated aluminum rod cross-over drive line assembly! No possibility of loose connections, cleats or broken drive line sections. One continuous non-breakable piece of rod criss-crossed thru an amazingly efficient polystyrene snap-lock spacer featuring the finest of all insulation against short-outs. A center air insulator space built into each spacer. One piece drive lines plus air insulated spacers, plus triple elements, plus metal shielded brackets, plus positive snap-in element guides, plus FINCO'S heavy duty square boom, plus UHF-VHF-FM reception and you have America's antenna design of tomorrow!

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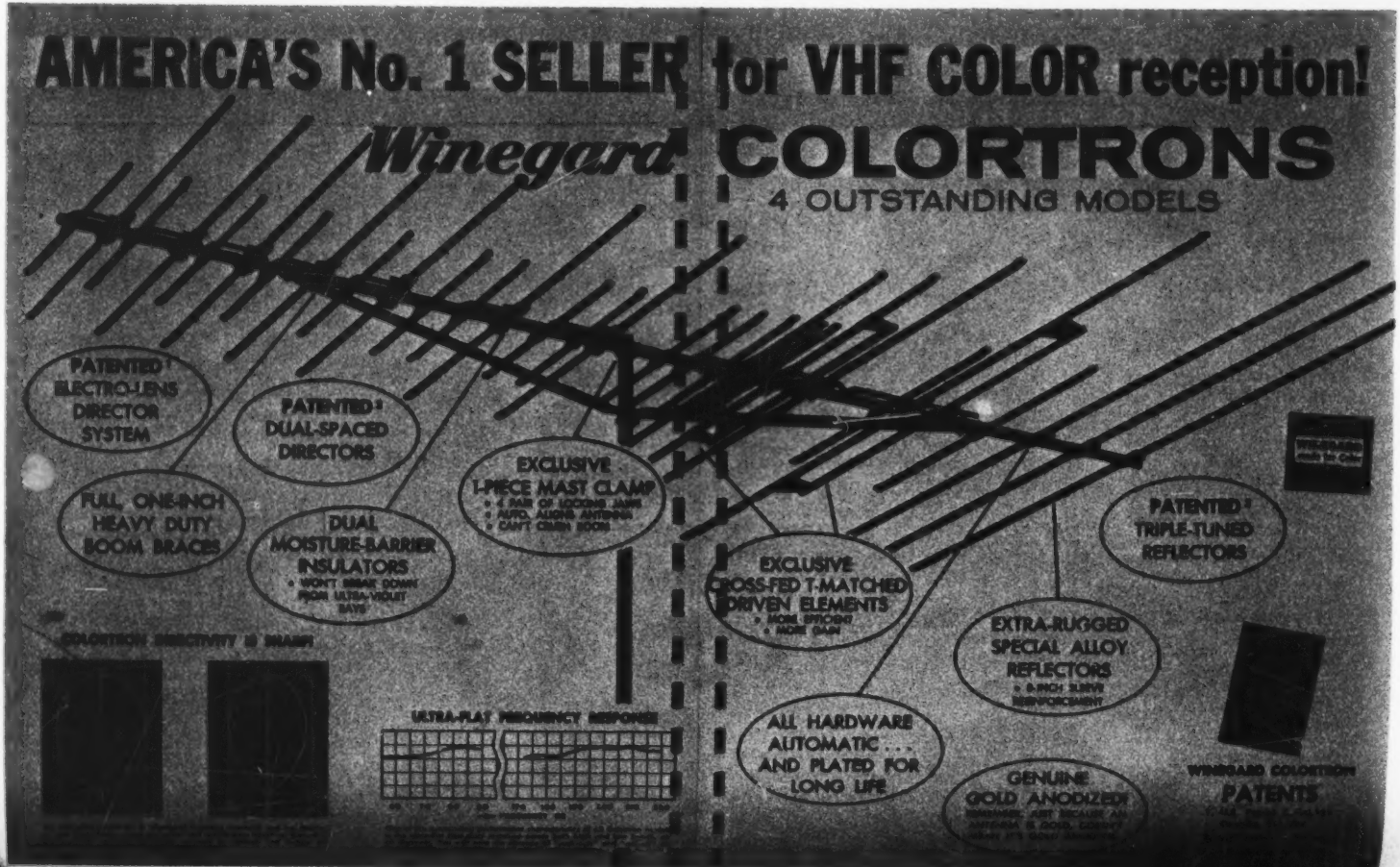
4 OUTSTANDING MODELS



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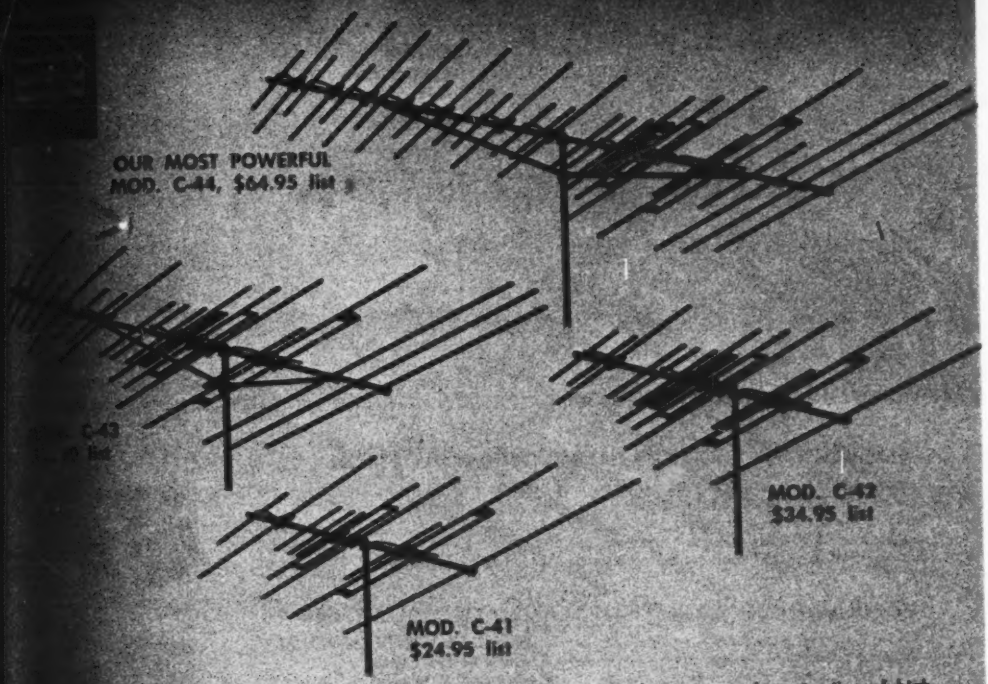


## ...e previous page . . .

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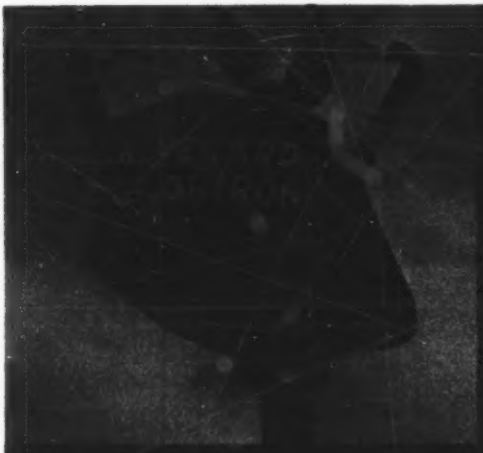
... solution color because of the ultra-flat fre... plus or minus ½ db across any 6MC chan... that there are no "suck-outs", no "roll-off" ...

All Colortron models feature rugged construction of high-tensile, gold anodized aluminum. They are built to last, built to permanently resist corrosion. Winegard backs up its claims for Colortron antennas by an exclusive Gold Band written factory guarantee of performance. This guarantee is packed in each and every Colortron carton.



# FOR THAT EXTRA POWER PUNCH, ADD A WINEGARD COLORTRON ANTENNA AMPLIFIER

## AMERICA'S FAVORITE TWIN NUVISTOR COLORTRON

Here's the all-channel VHF/FM antenna amplifier that can be used almost anywhere, even near local stations. Takes up to 400,000 microvolts of signal without overload. Helps pull in weak, distant stations, clears up snowy, grainy pictures. Designed for finest color reception and ideal for all signal areas, fringe, local or mixed. Choice of 300 and 75 ohm models. Attach easily to any VHF antenna.

## POPULAR, HIGH GAIN TWIN TRANSISTOR COLORTRON

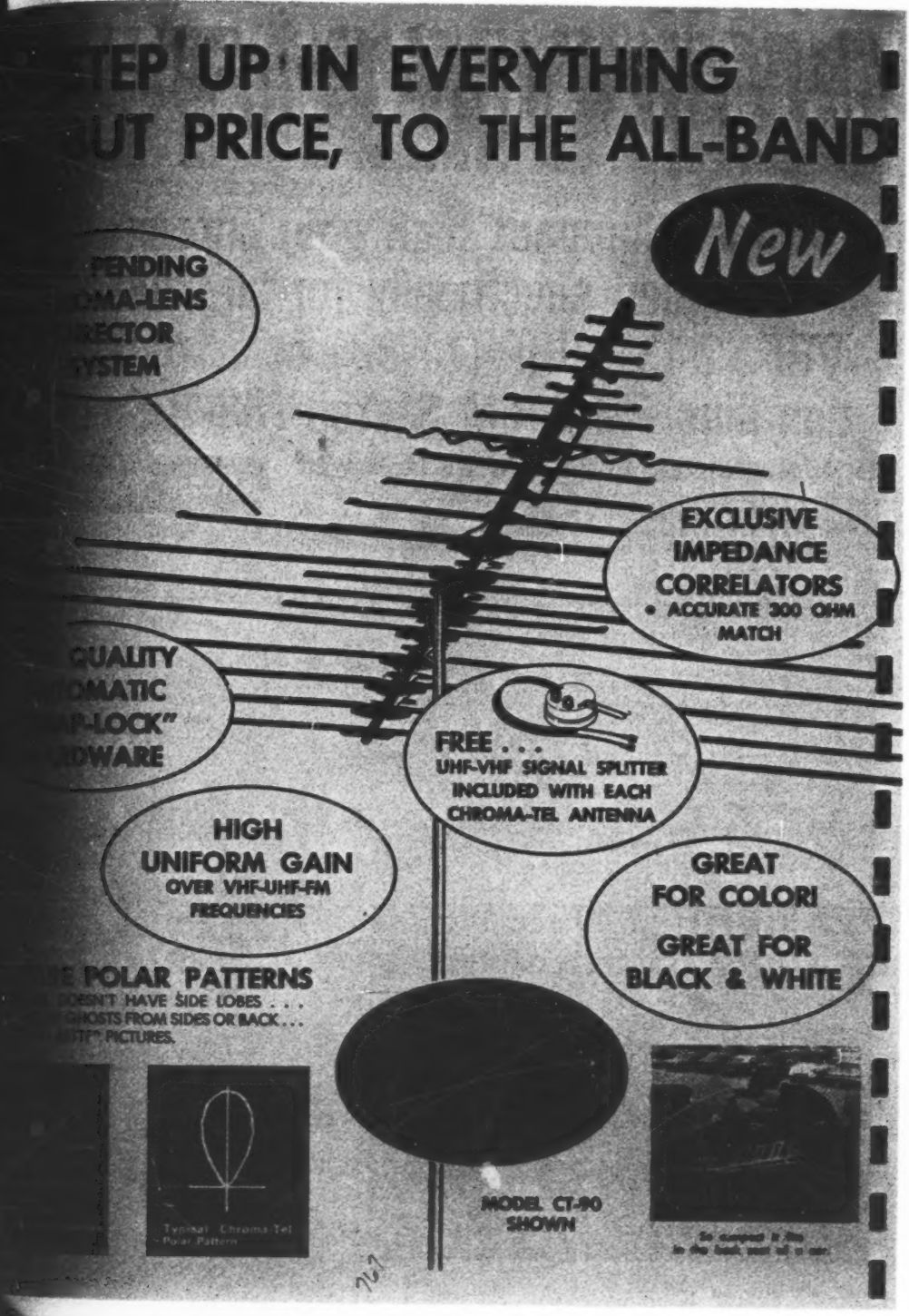
These installers who prefer transistorized amplifiers can choose from both 300 and 75 ohm models in Winegard's Colortron line. These units are unique in that they have as much gain on the high band as on the low band, with an equal boost to FM. You won't find this on other transistor antenna amplifiers. A Colortron preamplifier will make even the most sensitive antenna more powerful . . . letting you pull in stations not previously possible. Attaches to any VHF antenna.

## BIGGEST SELLING SINGLE TRANSISTOR PREAMPLIFIER

Winegard's "Red-Head" antenna amplifier is a popular choice of installers who need an inexpensive unit for weak signal area use. The "Red-Head" has been performance-proven for nearly three years with thousands of units delivering strong, clean signal for superior color and black and white reception. "Red-Head" is reliable, weather-proof and trouble-free. Fully protected against transistor "burn out" due to lightning flashes, static precipitation and AC line surges. 300 ohm only.

## TWO TRANSISTORIZED UHF ANTENNA PREAMPLIFIERS

The Winegard UHF-212 uses twin transistors to provide that extra gain frequently needed in deep fringe areas to pull in those weak channels. Exceptionally uniform frequency response on all UHF channels, including the translator band. Model UHF-110X is a high gain unit using a single transistor and recommended for areas where strong local signals are not present. Circuits of both preamplifiers are fully protected against damage from lightning flashes, precipitation static, etc. Both mount easily on any UHF antenna. Both have 300 ohm input and output.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New
PENDING
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ECTOR
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EXCLUSIVE
IMPEDANCE
CORRELATORS
• ACCURATE 300 OHM
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QUALITY
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SHOWN

# CHROMA-TEL

## Super-Compact high gain antenna designed specifically for all-band VHF (2-13), UHF (14-83) color reception plus FM & FM Stereo (88-108mc)

### THE ½ SIZE ANTENNA WITH FULL SIZE POWER

A big disadvantage of most all-band (UHF, VHF, FM) antennas is that they are larger and heavier than necessary. This is because they are really VHF antennas with UHF antennas tacked on the front end. Chroma-Tel isn't. It's super-compact and the first integrated antenna designed specifically for all-band UHF-VHF color operation.

How did we reduce the size so drastically without sacrificing performance? Two ways. First with our new Chroma-Loss Director System. With this unique system, we are, for the first time, able to intermix both VHF and UHF directors on the same linear plane without any sacrifice of performance.

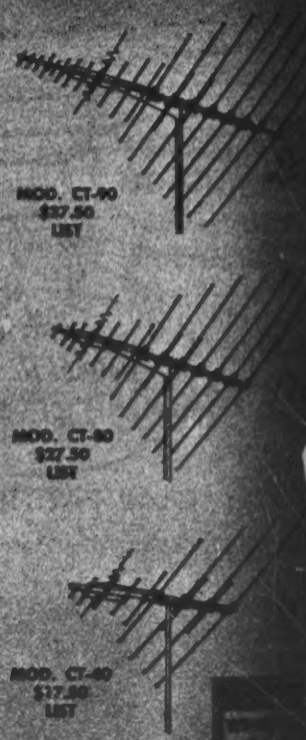
Second, with Impedance Correlators. These are the special phasing wires that automatically step up the impedance of Chroma-Tel's 72 ohm driven elements to 300 ohms. The correlators make sure each element has an accurate 300 ohm impedance at its given frequency. No other antennas with multiple driven elements have this! They also allow us to place the elements only 5½" apart instead of 10" to 14" apart as on other all-band antennas, reducing antenna length by one-half.

With the new Wingard Chroma-Tel antenna, we have eliminated half the bulk, half the wind loading, half the storage space, half the truck space, and half the weight . . . yet still have the best working, easiest installing UHF-VHF-FM antenna ever developed!

You give your customers a receiver installation that performs as well or better than any other all-band antenna on the market . . . and at a much lower price.

So compare performance, compare construction . . . find out for yourself what a great antenna value the Chroma-Tel is!

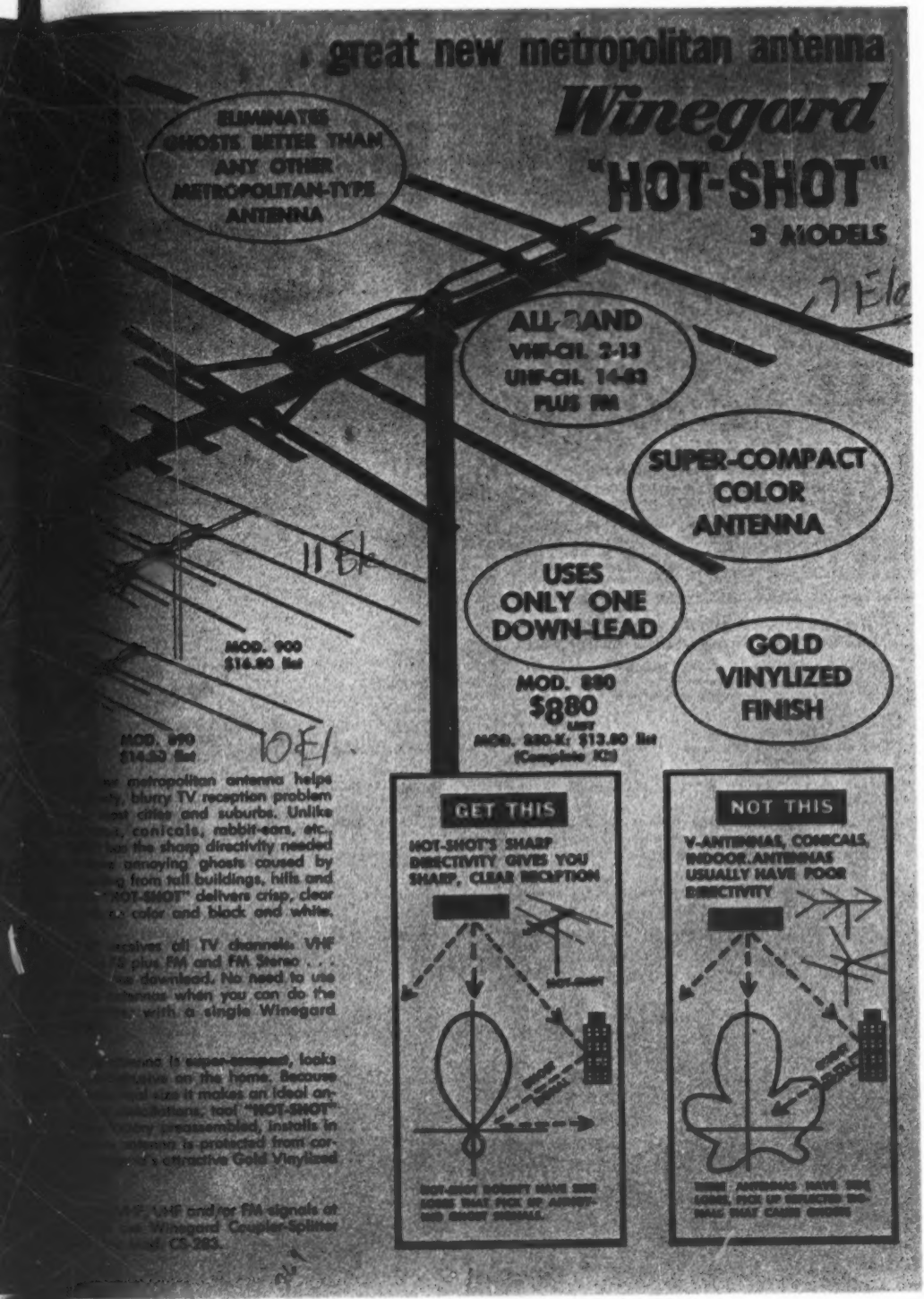
Choose from 3 sizes



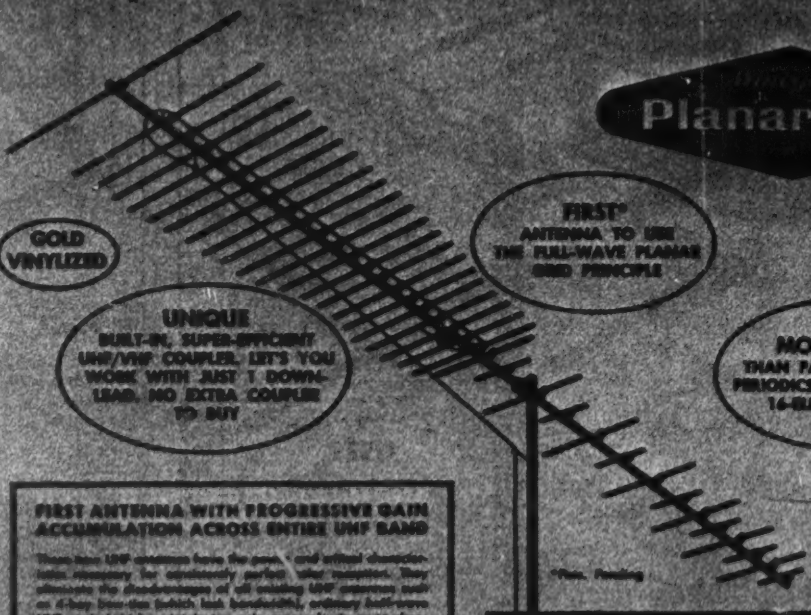
MOD. CT-90
$37.50
LIST

MOD. CT-80
$27.50
LIST

MOD. CT-40
$17.50
LIST


great new metropolitan antenna
Winegard
"HOT-SHOT"
3 MODELS
ELIMINATES GHOSTS BETTER THAN ANY OTHER METROPOLITAN-TYPE ANTENNA
ALL-BAND
VHF-CH. 2-13
UHF-CH. 14-83
PLUS FM
SUPER-COMPACT COLOR ANTENNA
USES ONLY ONE DOWN-LEAD
GOLD VINYLIZED FINISH
MOD. 900
$14.50 list
MOD. 880
$8.80
LIST
MOD. 880-K: $13.50 list
(Complete Kit)
GET THIS
HOT-SHOT'S SHARP DIRECTIVITY GIVES YOU SHARP, CLEAR RECEPTION
NOT THIS
V-ANTENNAS, CONICALS, INDOOR ANTENNAS USUALLY HAVE POOR DIRECTIVITY

# Winegard has the antennas you need for powerful UHF COLOR reception



Planar-Grid

GOLD VINYLIZED

FIRST* ANTENNA TO USE THE FULL-WAVE PLANAR GRID PRINCIPLE

UNIQUE BUILT-IN, SUPER-EFFICIENT UHF/VHF COUPLER. LET'S YOU WORK WITH JUST 1 DOWN-LEAD. NO EXTRA COUPLER TO BUY

MORE GAIN THAN PARABOLICS, LOG PERIODICS AND ORDINARY 14-ELEMENT YAGIS

MODEL U-[illegible] $39.95 list

*Pat. Pending

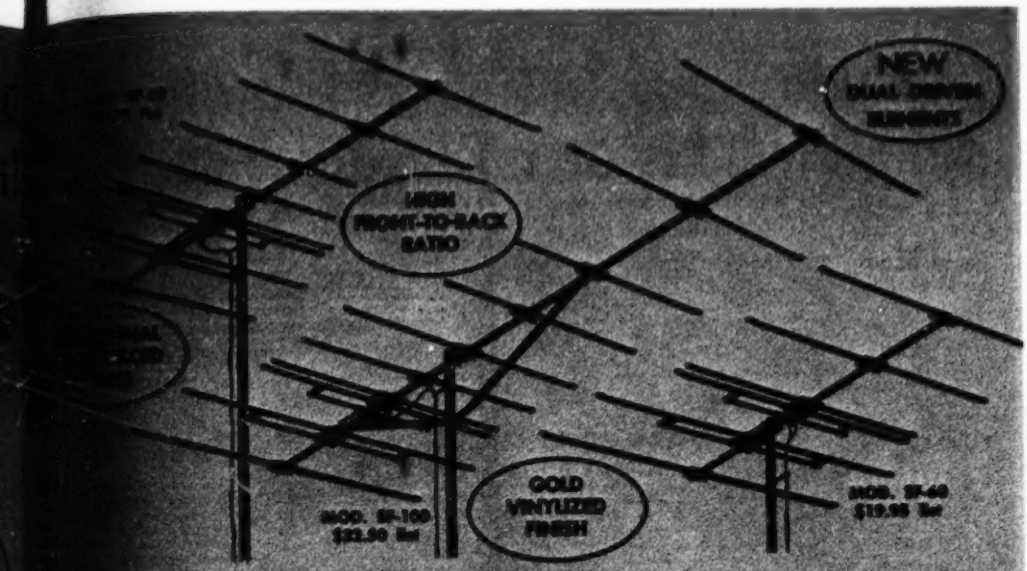
FIRST ANTENNA WITH PROGRESSIVE GAIN ACCUMULATION ACROSS ENTIRE UHF BAND

[illegible]

CHOOSE FROM FIVE POWERFUL MOD[illegible]

NEW "CONTROLLED INCIDENT WAVE" ANTENNA

GOLD VINYLIZED




# ...3 Stereotrons to solve FM reception problems

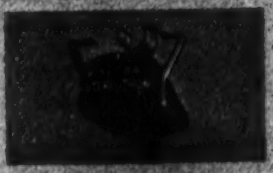
**...E DISTANCE . . . MORE STATIONS ... TRUE FIDELITY FM STEREO!**

...ntenna can make a world of difference in both ... of FM reception and the number of stations you ... receive. Winegard Stereotron antennas are designed ... one purpose in mind: to give you finest possible ... the greatest number of stations.

...ls are extremely high gain and have the highly ... pattern necessary to eliminate noise and multi- ... which are especially detrimental to good FM ... new Winegard models have dual driven elements for very high front-to-back ratio and the frequency response is flat across the entire FM band of 88-108 megacycles. All 9 new models are completely factory preassembled for quick and easy installation. Several other FM antenna models are also available from Winegard.

**For Super-Power, Add a Stereotron Preamplifier**

For an additional 15 db gain, add a Winegard twin-receiver Stereotron amplifier to your FM antenna. Both 300 ohm and 75 ohm models. Take up to 200,000 microvolts of signal to prevent cross modulation, overload and interference.

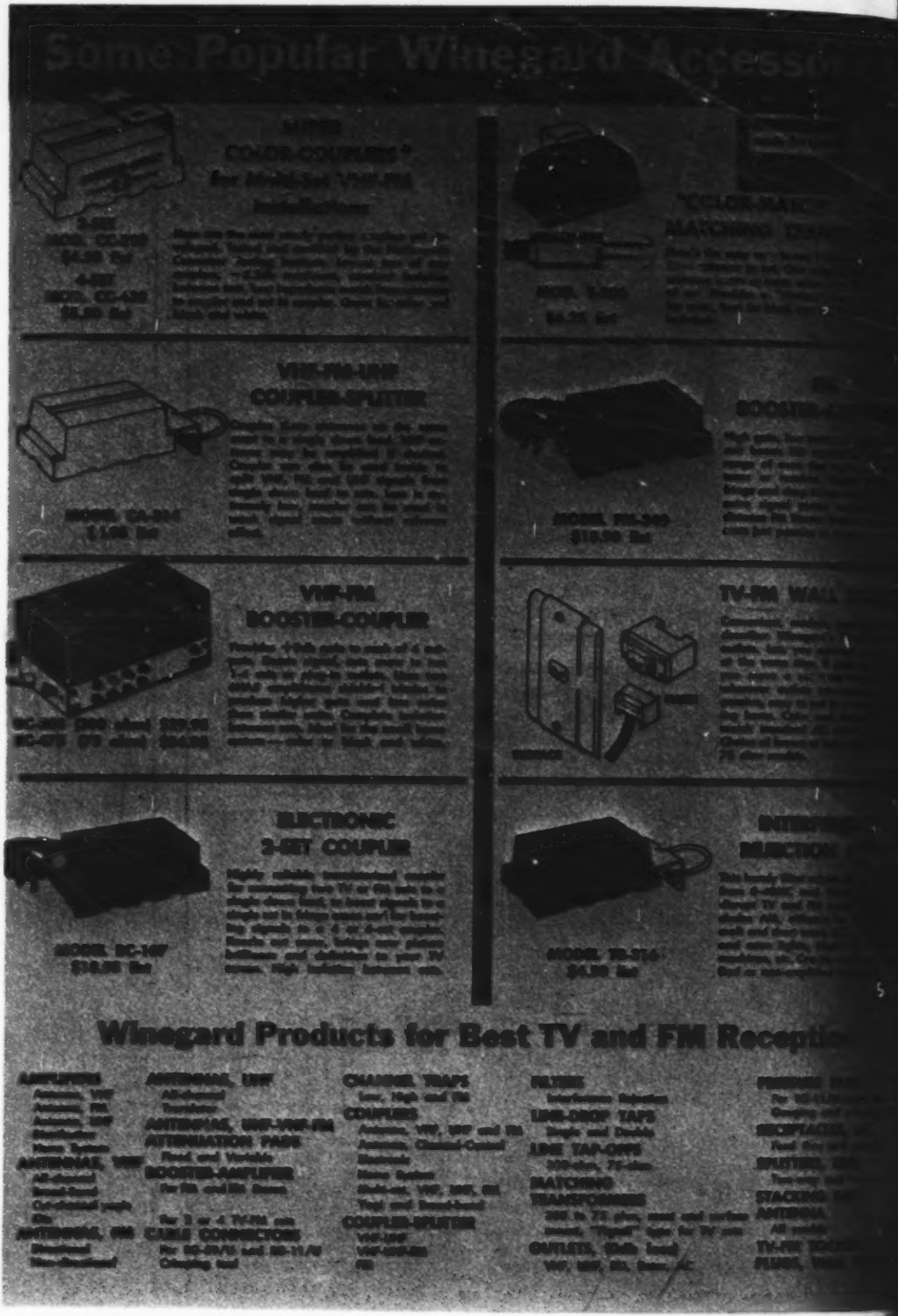


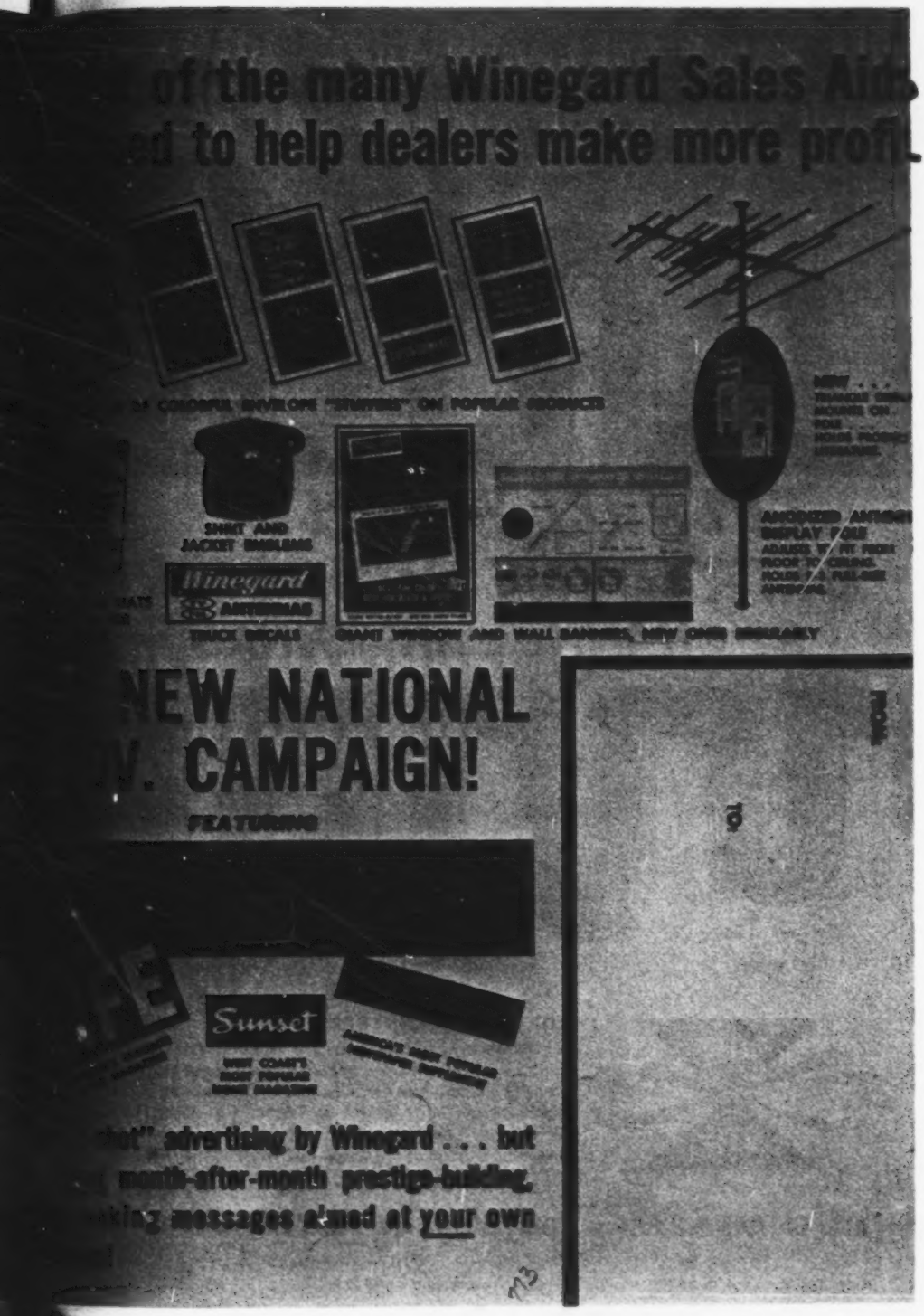
## Installing Master Antenna Systems is Easier and more profitable with Winegard Equipment

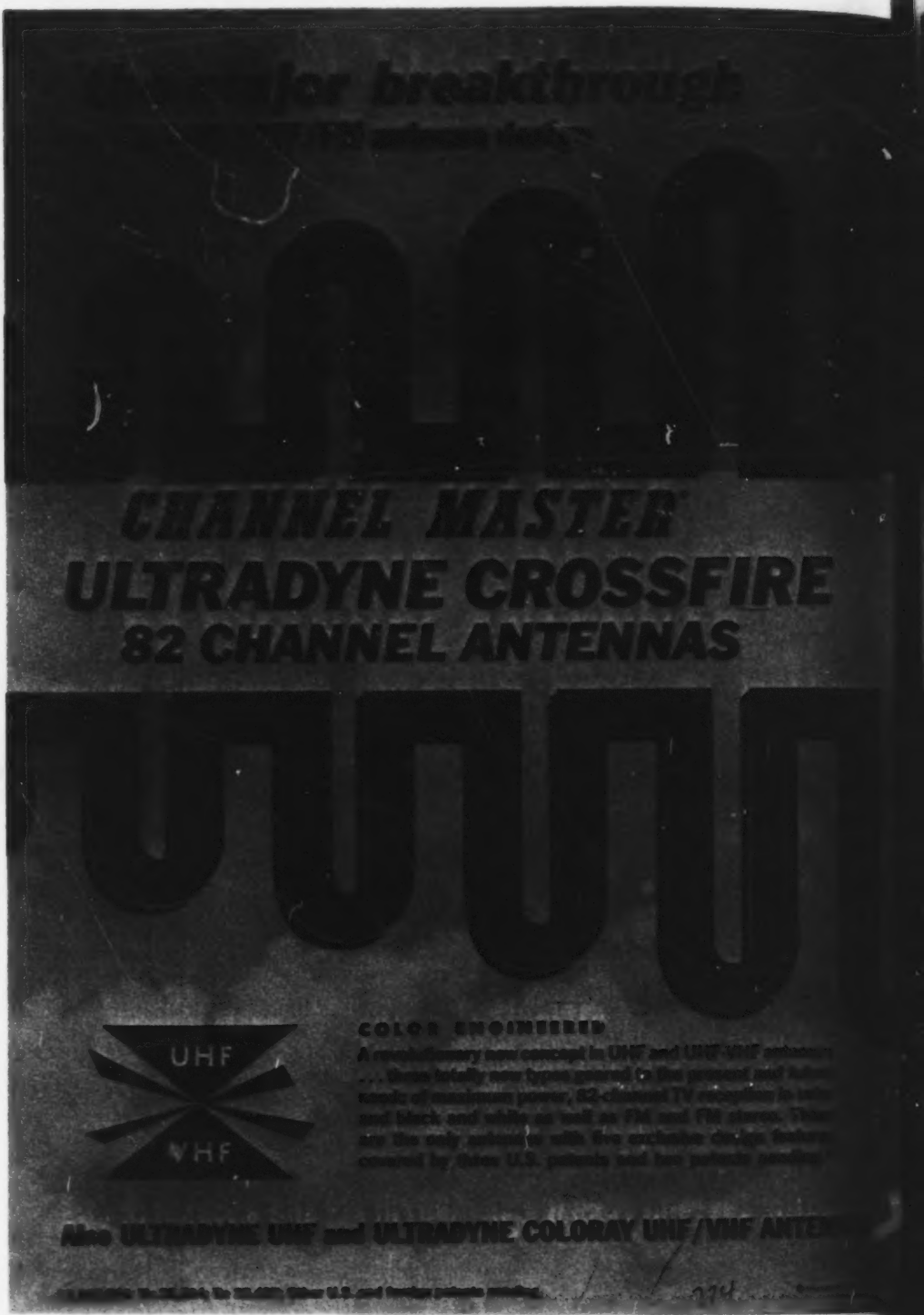
- **FREE SYSTEM PLANNING GUIDE**
- **FREE CHECKING AND LAYOUT SERVICE**

The trend to master antenna systems for commercial buildings and distribution systems for private homes has been growing by leaps and bounds. Today, Sentinel Winegard has taken the mystery and complexity out of such systems, even and more complex specialists are installing them with ease and profit.

Not only does Winegard produce all necessary components, but this company offers the installer a complete engineering service at no charge. The key to this service is the Master Antenna System Planning Guide available from your Winegard distributor. The installer can send his completed planning guide to Winegard system specialists for checking and recommendations . . . or, he can request Winegard to actually lay out a system for him. In addition, Winegard offers free "TV Signal Data Charts", "System Templates" for professional layout and "Test-Finder" for channel combining for equipment selection. The result is that every dealer gets full advantage of our true systems service.


Some Popular Winegard Accesso
VHF-FM-UHF
COUPLER-SPLITTER
VHF-FM
BOOSTER-COUPLER
ELECTRONIC
2-SET COUPLER
Winegard Products for Best TV and FM Recepti


of the many Winegard Sales Aids
ed to help dealers make more profi
SHIRT AND JACKET EMBLEMS
Winegard
TRUCK DECALS
GIANT WINDOW AND WALL BANNERS, NEW ONES REGULARLY
NEW NATIONAL
CAMPAIGN!
Sunset
advertising by Winegard . . . but
month-after-month prestige-building,
messages aimed at your own

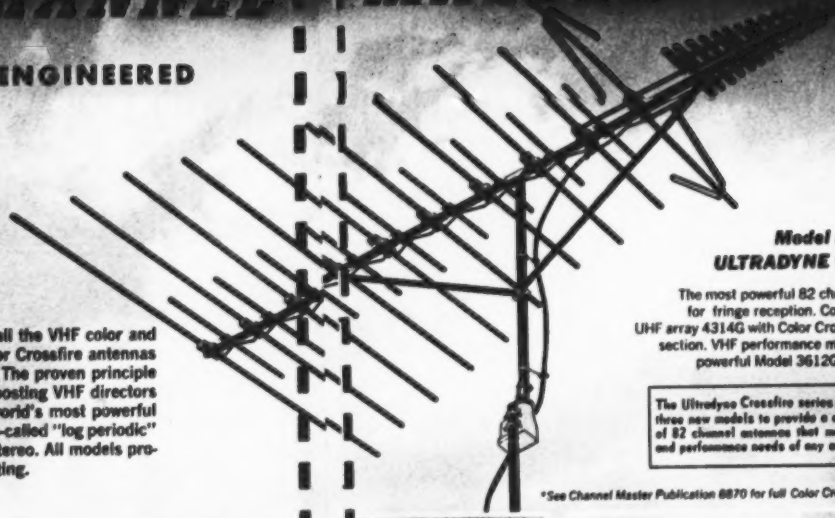

CHANNEL MASTER
ULTRADYNE CROSSFIRE
82 CHANNEL ANTENNAS
UHF
VHF

VHF

COLOR ENGINEERED

# ULTRADYNE CROSSFIRE ANTENNAS

**Combination UHF/VHF, TV/FM antennas with all the VHF color and black and white reception power of famous Color Crossfire antennas *plus* the amazing new ULTRADYNE UHF array. The proven principle of proportional energy absorption and signal-boosting VHF directors make ULTRADYNE CROSSFIRE antennas the world's most powerful 82 channel antennas available (outperforming so-called "log periodic" types) for color, black and white, FM, and FM stereo. All models protected with Channel Master's E.P.C. golden coating.**

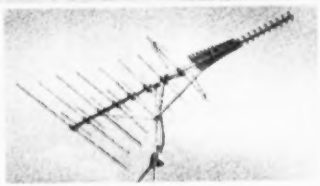


***Model 3632G***
***ULTRADYNE CROSSFIRE***

The most powerful 82 channel antenna . . . for fringe reception. Combines Ultradyne UHF array 4314G with Color Crossfire 3612G VHF section. VHF performance matches that of the powerful Model 3612G Color Crossfire.*

The Ultradyne Crossfire series now includes three new models to provide a complete line of 82 channel antennas that meet the price and performance needs of any area.

*See Channel Master Publication 6870 for full Color Crossfire performance data.

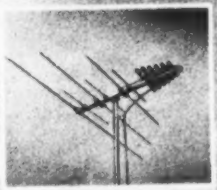


**Model 3632G** - Near fringe model combining 4314G Ultradyne with 3613G Color Crossfire. VHF performance same as 3613G

**Model 3634G** - A suburban model combining 4314G Ultradyne with 3614G Color Crossfire. VHF performance same as 3614G.

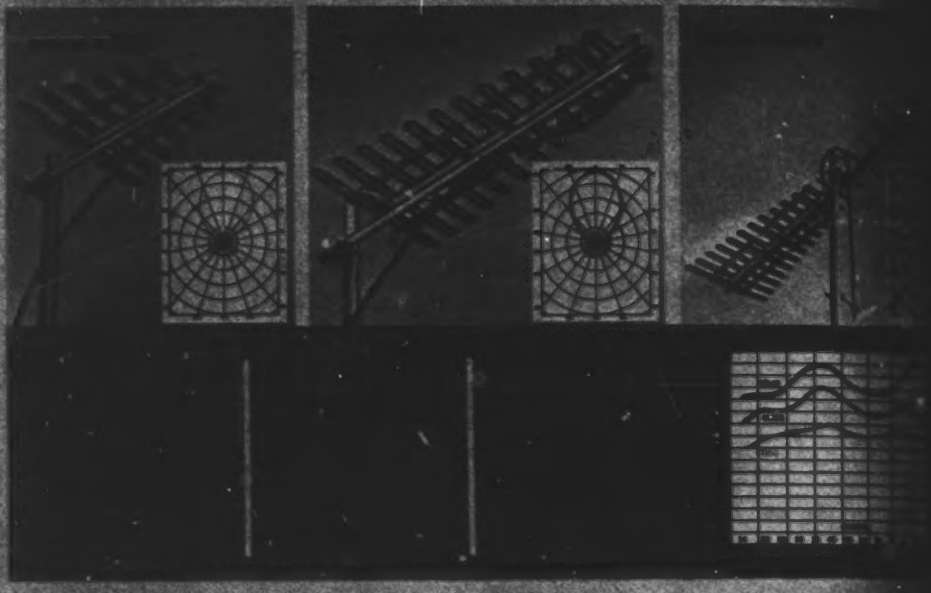
**Model 3634G** - Combines new 4315G Ultradyne with 3614G Color Crossfire for same VHF gain as model 3634G, but lower UHF gain.

**Model 3632G** - Combines new 4315G Ultradyne with 3613G Color Crossfire for excellent suburban reception.



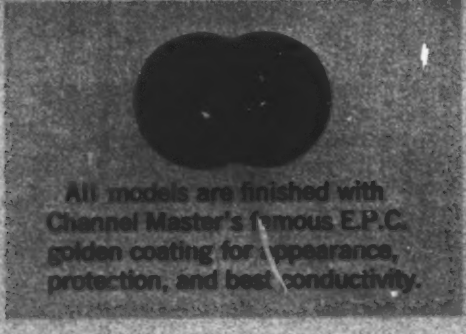
**Model 3648G** - Combines new 4315G Ultradyne with special extra element Color Crossfire array for outstanding metropolitan performance.

# NEW CHANNEL MASTER ULTRADYNE UHF ANTENNA



**The first antennas in UHF history to provide automatic impedance match with any 300 ohm VHF antenna . . . no coupler required.**

*Because of its unique 300 ohm charac... dyne UHF antennas may be combined ... VHF antennas to meet unusual reception ... covered by the standard Ultradyne C... tions. In this illustration, an Ultradyne ... mounted on the same mast with a 3610C ... and aimed at UHF stations. The pre... fire is pointed in a different direction ... VHF reception. No coupler is required.*



All models are finished with Channel Master's famous E.P.C. golden coating for appearance, protection, and best conductivity.

776

# THE ULTRADYNE WORKS

...to a transmission line. In a logarithmic coil, varying the diameter will not create large incremental changes in impedance. If there were a way to add a sufficiently large inductance to this type of antenna, its impedance could be raised above its present level of approximately 100 ohms. As it is, these antennas, because of their low impedance, create serious transmission when tied to other antennas or to 300 ohm transmission line and cause losses in the entire system.

The Ultradyne antenna overcomes this problem by making both the transmission line and the dipoles of a continuous one piece stamped strip. The spacing, the width of the strips, and the thickness of the strips have been carefully chosen so that the capacitance of the dipoles across the line, as well as the inductance which this type of folded dipole has and which a straight length of wire lacks, result in an impedance of 300 ohms, exactly the value required to match a length of twin lead or a well made VHF antenna. (See Figure C). As a result, the Ultradyne antenna eliminates the need for a UHF/VHF coupler at the antenna.

While the above explains the impedance characteristics of the Ultradyne antenna, it does not account for the fact that this antenna has higher gain than a log periodic antenna of the same number of elements, regardless of whether the elements are of fixed or varying spacing. A 12-element log periodic antenna covering the UHF band, whether fed by a transposed type of harness or parallel harness with dipoles transposed, will have dipole lengths in the array from 4½" to 12½".

FIGURE D

FIGURE E

(See Figure D). The Ultradyne antenna has dipoles from approximately 7½" to 16" in length. (See Figure E). The method of construction of the dipoles and harness from wide strip material enables the antenna to be longer and to have a much greater capture area. This capture area is from 25% to 66% greater than the conventional log periodic antenna of this type, and it is obvious that this larger capture area will provide greater gain.

FIGURE A

FIGURE B

FIGURE C

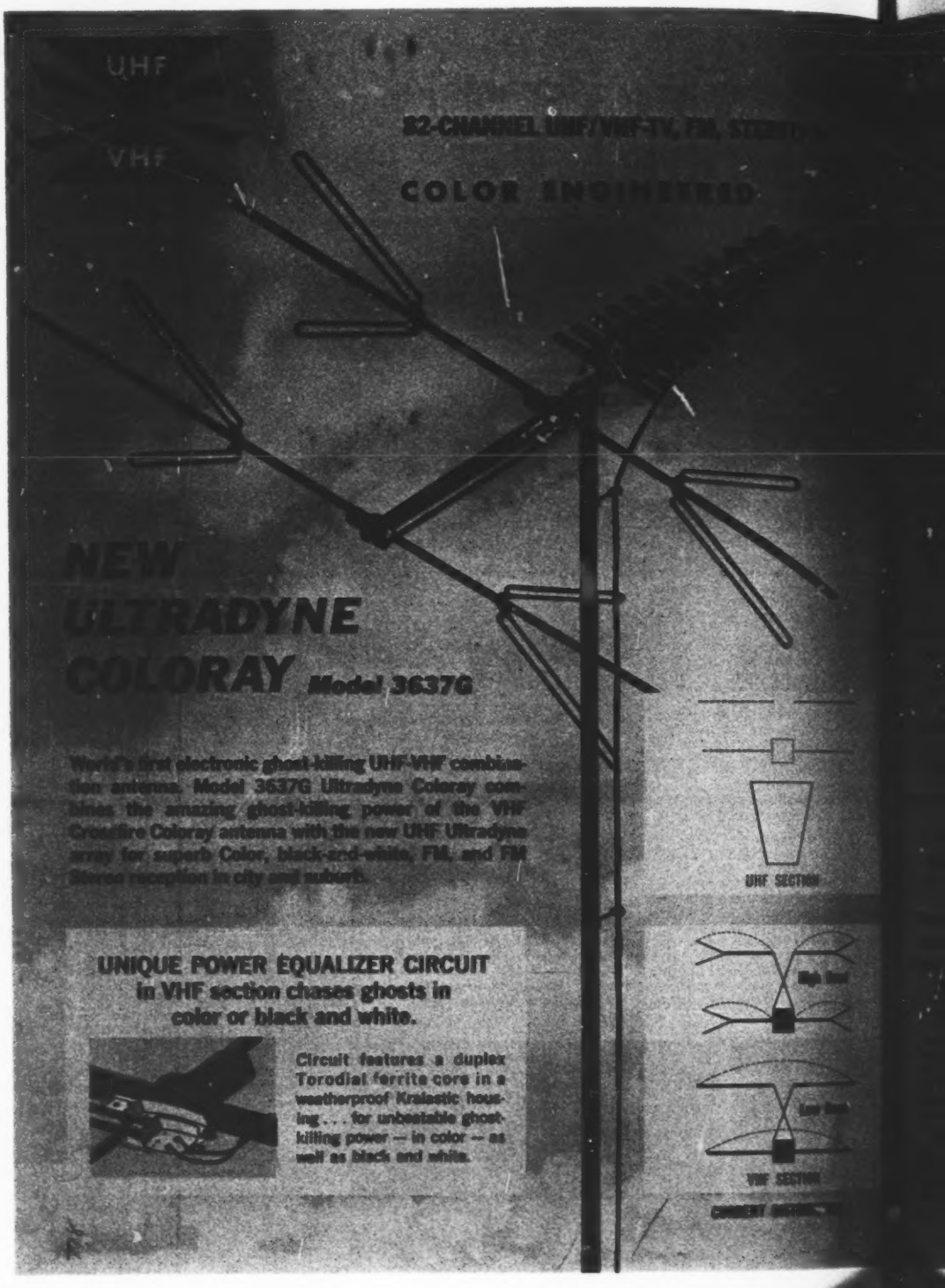
FIGURE F

FIGURE G

FIGURE H

One of the more surprising aspects of the Ultradyne antenna is the fact that at first glance it seems to have eliminated the transposed harness. However, this is not actually true. The key point to bear in mind is that instead of a straight dipole each element is a folded dipole. Each half of the folded dipole in this application can be considered as a length of shorted transmission line in which the voltage at the end of each conductor is equal and opposite. (See Figure F.). The spacing between dipoles is rather small compared to the length of the dipole, and so the feed points of adjacent dipoles can be considered as having virtually the same potential. The result is that any pair of dipoles are out of phase with each other. (See Figure G). a condition which is created in the so-called log periodic types by transposing the harness. (See Figure H).

The above considerations have enabled the Channel Master Engineering Department to design an antenna not only unique electronically but also unique mechanically. Each half of the array of 12 elements is stamped out of a single sheet. This fact completely eliminates electrical connections along the length of the antenna, and insures that the precise impedance calculations will never vary in production. It also permits the production of an antenna which is extremely light in weight, rugged, and corrosion proof. The Ultradyne antenna represents a great step forward in the antenna art.


UHF
VHF
COLOR ENGINEERED
NEW
ULTRADYNE
COLORAY Model 3637G
World's first electronic ghost-killing UHF-VHF combination antenna. Model 3637G Ultradyne Coloray combines the amazing ghost-killing power of the VHF Crossfire Coloray antenna with the new UHF Ultradyne array for superb Color, black-and-white, FM, and FM Stereo reception in city and suburb.
UHF SECTION
UNIQUE POWER EQUALIZER CIRCUIT
in VHF section chases ghosts in
color or black and white.
Circuit features a duplex Torodial ferrite core in a weatherproof Kralastic housing . . . for unbeatable ghost-killing power — in color — as well as black and white.
VHF SECTION

# ...HED ACCESSORIES

## ...NNEL MASTER ... for the most perfect UHF, VHF, ... and white, FM, and FM stereo reception possible in any area.

**ROTATORS** . . . All weather, on-target aiming. An improved reception extra for color and a must on combination antennas where VHF, UHF, and FM stations are located in different directions.

**CRESTWOOD DELUXE AUTOMATIC TENN-A-LINER** with control housing in fine furniture walnut cabinet. Model 9516. Precise aiming within one degree of station location.

**AUTOMATIC TENN-A-LINER** Model 9524. Except for wood cabinet, same features as the Crestwood.

**COMPASS TENN-A-LINER** Model 9520. Manually-controlled. Otherwise, same performance features as Automatic Tenn-A-Liner.

**...ADYNE and ULTRADYNE CROSSFIRE 75 OHM CONVERSION KITS**

...odel 0035A)
...AXIAL CABLE (RG-59/U)
...to 300 ohm
...TRANSFORMER (model 7180)
...with FITTINGS and
...GROUNDING CLAMP (model 7198)

Fittings and Balun Attached

Model 9531A with 25' RG-59/U

Model 9532A with 50' RG-59/U

Model 9533A with 75' RG-59/U

Model 9534A with 100' RG-59/U

...XIAL
...DING
...the set by
...a ground
...ch-fit outlets
...home.

...model 7198
...lightning protec-
...to co-ax installa-
...grounding prongs
...jacket and
...of co-ax . . .
...good ground.
...ground wire.
...better Model
...ground rod
...better Model
...model 7198.

### 300 OHM TRANSMISSION LINE

MODEL 9567 **BLACK JACKET FIGURE 8 FOAM TWINLEAD** has maximum resistance to ultraviolet light. Best for 82 channel reception. Foam covered 20-gauge pure copper stranded wire in solid polyethylene maintains constant impedance and low loss. Available in 500' spools or hanks (10 per pkg) as follows:

- Model 9575 75' - Model 9579 150'

MODEL 9550 **FOAM TWINLEAD.** Brown, foam covered, 20 gauge stranded copper. 500' spools and 10 per pkg hanks as follows:

- Model 9553 75' - Model 9554 150'

779

# CHANNEL MASTER
## UHF-VHF ACCESSORIES

COLOR ENGINEERED

**UHF/VHF/FM BALUN AND MATCHING TRANSFORMER**

Specially designed to convert any 300 ohm UHF-VHF installation to 75 ohm transmission line where interference is a problem in strong signal areas.

**Model 0436A 82 CHANNEL PLUS FM ANTENNA-MOUNTED BALUN.** Mounts directly on Ultra-dyne Crossfire terminals, OR ANY 300 ohm antenna. Virtually no loss (less than .5 db). Outstanding impedence match (VSWR: less then 1.1 across the entire band). Balanced to unbalanced ratio better then 30 db. Weather-proof Kralastic housing. "F" type coaxial connector and weather boot supplied.

**Model 7180 82 CHANNEL PLUS FM MATCHING TRANSFORMER.** The industry's lowest priced, MATV quality transformer. 75 ohm input 300 ohm output.

For indoor mounting only. Compact and lightweight, this sturdy plastic unit is designed for mounting behind 300 ohm TV sets in coaxial installations. Ivory colored. VSWR 1.25. Solderless plug provided.

**UHF/VHF/FM BAND SPLITTERS AND SET COUPLERS**

Band splitters are set-mounted units to separate UHF and VHF signals from combination antenna's single transmission line without loss. Couplers are designed for multi-set use on all 82 channels and FM.

**Model 0832 BAND SPLITTER**
300 ohm input and two 300 ohm outputs, one for UHF and one for VHF.

**Model 0848 BAND SPLITTER WITH TRANSFORMER.**
75 ohm input and two 300 ohm outputs, one for UHF and one for VHF.

**Model 0846 TWO-SET COUPLER**
300 ohm input and two 300 ohm outputs. 82 channels and FM.

**Model 0844 FOUR-SET COUPLER**
300 ohm input and four 300 ohm outputs. 82 channels and FM.

**Model 0847 TWO-SET COUPLER**
75 ohm input and two 75 ohm outputs. 82 channels and FM.

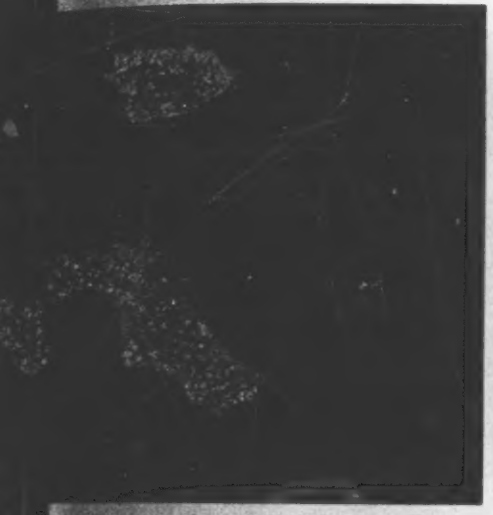
**Model 0845 FOUR-SET COUPLER**
75 ohm input and four 75 ohm outputs. 82 channels and FM.

DISTRIBUTED BY:

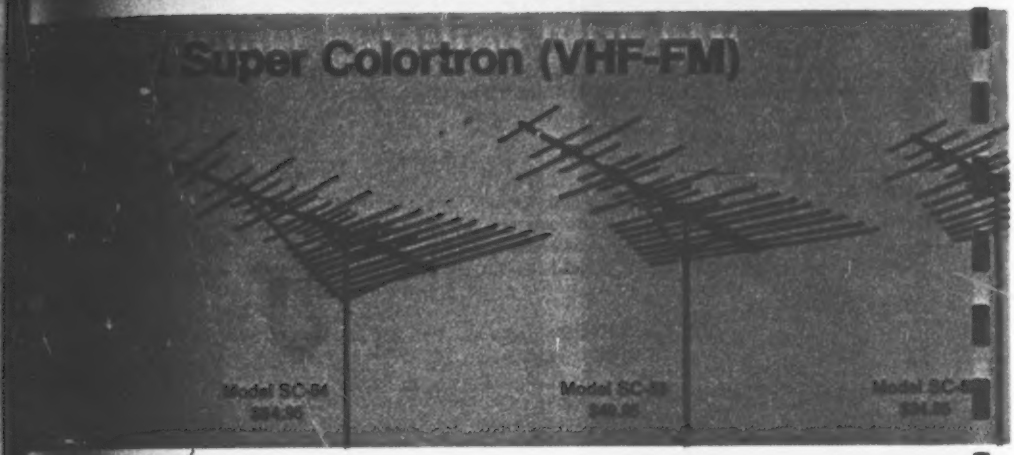
CHANNEL MASTER
ELLENVILLE, NEW YORK

# ntroducing the world's first
# UPER COMPACT
# OTAL DESIGN ANTENNAS
# INEGARD'S NEW ELECTRONIC
# UPER COLORTRONS

e 82-Channel Models • Four VHF/FM Models • Three UHF Models
o revolutionary in design and concept, they have 7 patents and patents pending



TOTAL ELECTRONIC DESIGN!
Wingfoot


Super Colortron (VHF-FM)

# Winegard Company

Manufacturer of TV Antenna Systems 3000 Kirkwood Street, Burlington, Iowa 52601 Area Code (319)

SUPER COLORTRON IS HERE!

January 1967

The people at Winegard Company are charged with excitement! Our engineers. Our sales people. Our production force. Our advertising personnel. Each of us eager to tell you about our revolutionary new series of Super Colortron antennas. 12 great models -- so totally new in design and concept they have 7 patents and patents pending. PLUS -- 6 Super Colortron solid-state, printed circuit cartridge amplifiers, 2 75-ohm terminal cartridge boards and a unique Color Spectrum Filter!

We've been working on these Super Colortron products for many months. Refining them. Perfecting them. Making certain they would be the most advanced antennas and amplifiers ever offered by Winegard or anyone else.

Now all the pieces have fallen into place. Tools, dies, molds and special production machinery are completed. Pilot production runs are over. Field testing of production models is concluded. And Super Colortrons are rolling off our assembly lines.

Finished goods are in stock ready for shipment.

Potent new sales literature and display aids are ready to go to work for you and your dealers. Full color ads are ready for appearance in dealer magazines in late February and March. And of course plans are underway for a dynamic consumer advertising campaign...a field in which Winegard has been the industry leader for more than 10 years.

In short, we have spared nothing to make the introduction of Super Colortron antennas and amplifiers the most important event in Winegard history!

Selling Super Colortron antennas promises to be one of the easiest jobs you've ever tackled. For these are the total design antennas. All new in construction and performance. All new from the exclusive built-in cartridge housing to the shape of the boom. So many features you'll find it a cinch to switch competitive dealers to Winegard.

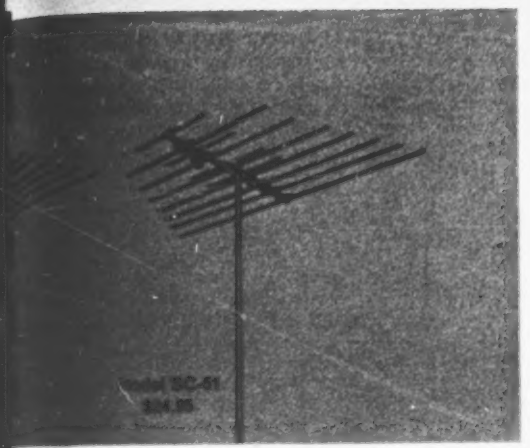
After you read the enclosed literature and inspect the special "hand sample," we think you'll share our excitement and enthusiasm. We know you will want to get Super Colortron antennas and amplifiers into your store as quickly as possible.

So call us collect or see your Winegard salesman. And we'll expedite your order.

Cordially,

Robert M. Fleming, Jr.
Marketing Manager

P.S. The Super Colortron price sheet shows which antennas each model replaces. No current models will be discontinued immediately, but several will be "phased out" by June, 1967.



## Winegard Gold Bond Guarantee

**GUARANTEE**—The Winegard antenna is guaranteed for one year from date of installation to provide clear, pleasure TV reception at your location on your black and white or color television when properly installed. Should the antenna not perform as expected, the Winegard Company will make it right to your satisfaction, replace it or refund your purchase price.

**OUR RESPONSIBILITY**—Winegard antennas are electronic equipment and must be installed according to instructions enclosed in the carton. This guarantee is valid only if the user mails the attached registration card within 10 days of installation. If you are not satisfied within thirty days of installation, write directly to the Winegard Company. They will correct your complaint promptly.

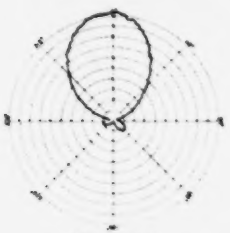
**Winegard**
ANTENNA SYSTEMS

WINEGARD COMPANY, 3000 KIRKWOOD STREET, BURLINGTON, IOWA 52601

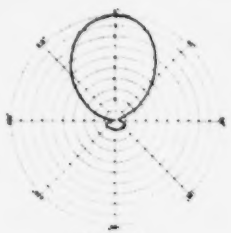
# The Amazing Winegard SUPER COLORTRONS make a difference you can really see!

Winegard Super Colortrons have super directivity, too. Super sharp to reject undesired, interfering signals. And super sharp to pick-up *only* the channels you want for consistently clean, interference-free reception —in color and black & white. See the difference for yourself. Note the unequalled front-to-back ratio on all 82 channels—and the unequalled ghost and interference-cutting directivity on all 82 channels.

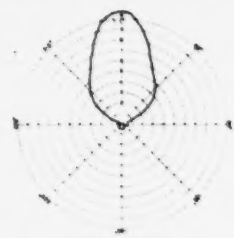
**IMPORTANT**: The polar patterns shown below for the Super Colortron (Model SC-83) are exact reproductions of the originals taken with a Leeds and Northrup automatic electronic recording device.



Channel 2



Channel 6



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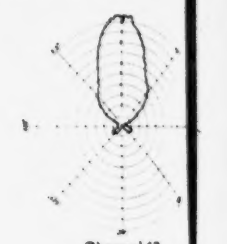

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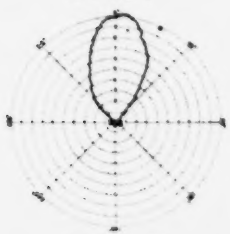

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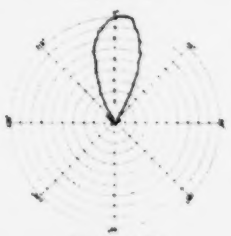

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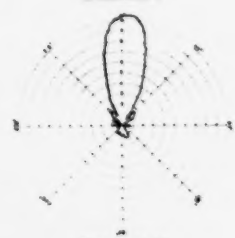

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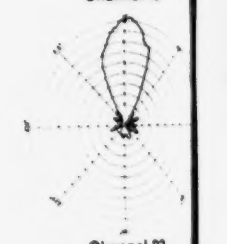

Channel 83

Winegard
ANTENNA SYSTEMS

**Winegard Company, 3000 Kirkwood Street**
**Burlington, Iowa 52601**

Printed in U.S.A.

Form

Supreme Court of the United States

# Supreme Court of the United States

*No.* 338 ----- , *October Term, 19* 70

Blonder-Tongue Laboratories, Inc.,

Petitioner,

v.

University of Illinois Foundation, et al.

ORDER ALLOWING CERTIORARI. Filed October 19, 1970

The petition herein for a writ of certiorari to the United States Court of Appeals for the Seventh Circuit is granted.

FILE COPY

Supreme Court, U.S.
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E. ROBERT SEAVER, CLERK

IN THE

# Supreme Court of the United States

October Term, 1970

No. 338

BLONDER-TONGUE LABORATORIES, INC.,
*Petitioner,*

vs.

UNIVERSITY OF ILLINOIS FOUNDATION, and
JFD ELECTRONICS CORPORATION,
*Respondents.*

ON WRIT OF CERTIORARI TO THE UNITED STATES COURT OF APPEALS FOR THE SEVENTH CIRCUIT

## SUPPLEMENTAL APPENDIX

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# JFD SUPPLEMENTAL APPENDIX

## Preface

*The Petitioner's Brief cites parts of the record that were not designated by Petitioner's counsel and do not appear in the joint appendix. Additional citations to the record are required to support JFD's responsive argument and are referred to in the brief as (JA. ).*

## Excerpts from Transcript of Proceedings

[3] *Opening Statement on Behalf of Plaintiff, by Mr. Mann*

• • •

[10] The Court: Are you saying to me that the [11] evidence will reveal everything you are saying?

Mr. Mann: Yes, sir. The evidence will reveal that.

The Court: You are having in mind that this is an opening statement and not an argument?

Mr. Mann: Yes, your Honor. Exactly.

• • •

[35] *Opening Statement on Behalf of Counterclaim Defendant, by Mr. Berliner*

• • •

The Court: You are not getting into argument now?

Mr. Berliner: No.

• • •

[41] Edward F. Harris, a witness called by and on behalf of the plaintiff, having been first duly sworn, was examined and testified as follows:

• • •

[81] Now at this point I would also like to offer for identification Plaintiff's Exhibit No. 1 which is a soft copy of Isbell Patent—

The Court: You don't mean offer for identification; you mean offer in evidence.

Mr. Marshall: I am identifying it initially. I thought that was—

The Court: They have been identified, is that it?

Mr. Marshall: No, they haven't, your Honor.

The Court: They have been marked for identification?

[82] Mr. Marshall: They have been marked for identification, yes.

The Court: Then you want the witness to identify them?

Mr. Marshall: No, your Honor. I am merely going to hand them to your Honor. I thought that in view of your remarks—

The Court: I won't take them until we have taken them into evidence. If you have something marked as an exhibit, you may recite the numbers, show them to counsel, and if there is no objection, we will take them into evidence.

Mr. Marshall: That is what I am proposing to do, your Honor.

* * *

[103] *By Mr. Marshall:*

Q. In other words, it is your answer, then, Mr. Harris—

The Court: Let his answer stand.

Mr. Marshall: I am not going to paraphrase it.

The Court: We do not permit counsel to codify the answer or paraphrase it. I take the answer as the witness gives it.

* * *

[136] Q. Mr. Harris—

Mr. Marshall: Your Honor, at this particular time, in view of the informal discussion we had before the bar on Thursday, unless your Honor has some additional information which he would like to have as background, we have no further questions to [137] ask Mr. Harris at this time and turn him over to Mr. Rines.

The Court: Mr. Marshall, this is your lawsuit.

Mr. Marshall: I realize that, your Honor.

The Court: I am not here to develop a case for either the plaintiff or the defendant. If there is anything I have said here that provokes the notion in your head that I want some background—back-

ground doesn't mean anything to me. I told you my views about background the first day of this trial. Have you finished?

Mr. Marshall: I am finished with that remark.

* * *

---

[208] In the United States District Court

* * (Caption—66-C-567) * *

Before:

Julius J. Hoffman, *Judge*

Tuesday, January 2, 1968
2:00 o'clock p.m.

* * *

[240] Mr. Marshall: Your Honor, at this time we would like to introduce some documentary evidence. We have no more live witnesses.

[241] I would like to mark for identification Plaintiff's Exhibit No. 5-A, and it is a copy of an advertising brochure entitled, "Blonder-Tongue Golden Dart All-Channel UHF Antenna," bearing the designation, "YC-2015."

The Court: May I interrupt you to ask whether these exhibits, such as, for example, Plaintiff's 5-A, for identification, are going to be agreed to? Are they stipulated?

Mr. Marshall: Your Honor, we have indicated to the other side that we were going to use these, and there were no objections raised to them.

The Court: Well, I want the lawyers to say so. You, as the lawyer, are identifying some documents. You have a right to do that if there is a stipulation that they be admitted into evidence, but you can't identify them.

Mr. Marshall: No, your Honor, I am merely characterizing them.

The Court: As a matter of law. There is no objection to your identifying if there is a stipulation.

Mr. Marshall: There was a stipulation, your Honor, as I understand it, to the extent that there [242] were no objections to these particular—

The Court: In ordinary circumstances I would take a lawyer's word for that, but I must have the word of two lawyers to say that there is a stipulation that certain exhibits be admitted into evidence. That is just simple trial practice.

Mr. Rines: Your Honor, I don't remember any such stipulation.

Mr. Marshall: I would like to show it to Mr. Rines, your Honor.

The Court: You must negotiate a stipulation before trial.

Mr. Rines: Your Honor, all we agreed to in the stipulation—

The Court: I don't want to argue a stipulation. If there is a stipulation, the exhibits may be offered, and I will take them in. If there is no stipulation, I won't even let you offer them as stipulated.

Mr. Rines: Your Honor, there is no stipulation that they may be put in evidence as exhibits.

The Court: They may not be admitted.

Mr. Marshall: Your Honor, may I be heard?

[243] The Court: Yes.

Mr. Marshall: The stipulation said—

The Court: The stipulation is questioned. If it is questioned, I don't want to have to interpret stipulations.

Mr. Marshall: Your Honor, there is no question about the stipulation. This stipulation was entered as a court order and was entered as a pretrial order on or about March 1, 1967, by this Court, and if the Court so permits, I will read that particular paragraph going—

The Court: Do you dispute that statement?

Mr. Rines: No, your Honor, I stand by that stipulation, but it is not a stipulation that may be put in evidence.

The Court: You mean it was stipulated that the document was so identified?

Mr. Rines: Was correctly identified, your Honor, yes.

The Court: There is a vast difference.

Mr. Marshall: I agree, your Honor.

The Court: You may hold a copy of the Declaration of Independence there. Nobody will question its authenticity, but whether or not it [244] may be admitted is something else again. If you have a stipulation that a document be admitted into evidence, of course I will take it in. But in the face of objection on the ground that there is no such stipulation, I don't know what I can do about it.

* * *

[456] Dr. Raymond H. DuHamel, called as a witness by and on behalf of the plaintiff in rebuttal, having been first duly sworn, was examined and testified as follows:

* * *

[478] Mr. Marshall: Perhaps, your Honor, I might rephrase the question.

[479] The Court: You have asked for one specific thing, as I understand it—why.

Mr. Marshall: That's right, your Honor.

The Court: And the witness should then say "because of this," and then if you have another question that is suggested by his answer, perhaps you will ask it. But I don't think a witness may go on and on without answering a question. I just haven't the time for that.

Mr. Marshall: I agree, your Honor.

The Court: And it doesn't help your case any. There are so many Ph.D.s, Mr. Marshall, who think they are lecturing to a class. I am only one little student here who

must read all this stuff later, and until I get to the answer, it may take me ten minutes. When you multiply that by many, many questions, then you can see the huge consumption of time, unnecessary consumption of time.

Tell us why, if you can.

* * *

[703] Isaac S. Blonder, called as a witness by the Counter-claimant herein, having been first duly sworn, was examined and testified as follows:

* * *

[704] The Court: Do you expect me now, during the trial, to determine the sufficiency of the pleading?

Mr. Cass: No. I concede that, your Honor. It should have been brought by a motion. However, at the time, during the discovery, request was made repeatedly to identify the particular sections of the Anti-trust Act that were being violated. [705] This was not done in a formal pleading, and it seems to me that at this time the Court might well inquire as to what is going to be the position of the counterclaim defendant with respect to the anti-trust laws.

Otherwise—

The Court: There is no better way of hearing it than from the sworn testimony of—I don't know the position of this witness, but his name is included in the name of the defendant and the counterclaimant.

If you can't wait, if you are getting restive, I will ask Mr. Rines to hurry and get this evidence of alleged violations of the Sherman Act into evidence. You are a little late in asking for the details. That is a discovery matter that certainly should have been gone into under the Federal Rules of Civil Procedure.

Mr. Cass: Thank you, your Honor.

The Court: Or you could have taken depositions, perhaps the deposition of this very witness who now has taken the witness stand.

Mr. Cass: We did, your Honor.

The Court: I am a little bit interested myself, [706] but I can't take the time now to assist you with your discovery.

• • •

[710] Q. At what time approximately did Blonder-Tongue Laboratories start itself to manufacture antennas? A. I have manufactured antennas ever since I have been involved in television. I have made antennas for the laboratory, for myself, for my family and for friends since 1947.

[711] Q. When did Blonder-Tongue Laboratories first come out with commercial television antennas? A. In the fall of '63.

• • •

[737] Mr. Rines: • • •

I might say that in hundreds of cases I have tried I have never done this.

• • •

[750] Q. Who performed the test in the laboratory? A. Abraham Schenfeld.

Q. Is that the same Abraham Schenfeld that is the co-inventor of the Blonder-Schenfeld Patent in suit, Defendant's Exhibit 26? A. Yes.

Q. Is he still in your employ? A. No.

Q. Will you tell us approximately when he left the employ of Blonder-Tongue Laboratories? [751] A. He left the middle of the year '67.

Q. Do you know where he is now employed? A. JFD.

Q. The counterclaim defendant JFD? A. Yes.

• • •

[756] Q. Were tests performed of which you have any cognizance at Blonder-Tongue Laboratories as to the operation of the JFD antenna, Defendant's Exhibit 27-A? A. Yes.

Q. Under whose direction? A. Abraham Schenfeld.

The Court: Not under yours.

The Witness: Under my direction. I assigned Mr. Schenfeld, who directly was under by supervision, to perform these tests.

*By Mr. Rines:*

Q. Are you aware of the results of the tests? A. Yes.

* * *

[764] Q. Can you tell his Honor what were the duties [765] of Mr. Balash in connection with the position you have just identified prior to his leaving in the middle of 1966? A. Mr. Balash was in charge of our home products group which consisted of the antennas and related equipment for the home.

Q. And what was his job at that time? A. He was the manager of that program.

* * *

[766] Q. Who at Blonder-Tongue, if anyone, was responsible for determining the reasons that the antennas of Plaintiff's Exhibit 10 were not selling? A. The Director of Marketing, Dick Helhoski was in charge of the overall program. He assigned Mr. Balash to personally investigate and find [767] out why we were having these sales problems.

Q. Was Mr. Balash engaged in this investigation so far as you know at the time he left the employment with Blonder-Tongue and went to JFD? A. Yes.

Q. To your knowledge were any records or documents kept by Mr. Balash in connection with these investigations? A. Yes.

Q. Will you tell the Court where they are? A. I don't know.

Q. Have you looked for them? A. Yes, we did.

Q. When did you first look for them? A. The day after he left.

Q. The day after who left? A. Jerry Balash left the employ of our company.

Mr. Cass: Your Honor, I would object to this line of questioning because it still hasn't been proven exactly what reports we are talking about.

The Court: I agree that the questions and answers have no probative value, but please, sir, if you have an objection to a question, object to the question. I never deal in lines of inquiry. [768] Counsel skipped around in examining the witness. There is no definite line. I don't know how to rule on your objection to a line. I agree that some of these questions were objectionable but you did not object to the question.

Object and state your reason.

We have in the record here now that a search was made for certain records, what records the witness does not say, and they couldn't be found the day after a man named Balash left the employ of the witness' company.

Do you want that stricken?

Mr. Cass: Yes.

The Court: You move to strike the answers that I have paraphrased there?

Mr. Cass: I move to strike.

The Court: I will strike them.

• • •

[770] Q. Will you tell his Honor what records were they that you were unable to find the day after Mr. Balash left your employ for JFD? A. We could not find any

records of the correspondence, the inter-office correspondence or the correspondence with our customers. I do not know where they are.

Q. Were there any other records missing to your knowledge when he left? A. No.

• • •

[812] Q. Mr. Rines: Oh. I believe I will offer a [813] few more documents with regard to infringement.

Your Honor, I would like to offer in evidence for a different purpose the exhibit marked as Defendant's Exhibit 35 for identification as to which your Honor ruled in connection with the unfair competition count. It has been admitted that this is an advertisement relating to the JFD antennas of JFD, the counterclaim defendant. I submit, your Honor, that any admission of a party with regard to their structures, with regard to their relationship with the other co-defendant, which is in issue here, the Foundation, any admission is admissible.

The Court: Is it denied? Does JFD deny that they have some business dealings with the plaintiff?

Mr. Rines: The issue in this case is what kind of a relationship is that and the—

The Court: That exhibit doesn't on its face—

Mr. Rines: I believe it does, your Honor, it gives the history.

The Court: You haven't heard what I was going to say.

[814] Mr. Rines: Excuse me.

The Court: I have sustained the objection to the document. You didn't offer it for one particular purpose. You offered the exhibit and I ruled that it is not admissible for what I perceive to be good and valid reasons. There is nothing illegal about this JFD Company doing business with the plaintiff.

• • •

[824] Mr. Cass: Your Honor, at this particular time I would like to move to strike the testimony of Mr. Blonder as to the exhibit which was entered, D. 32. I understood that this exhibit was going to be offered to show the state of mind of customers in reaction to a certain ad.

The Court: He hasn't got around to that yet.

Mr. Cass: He hasn't gotten around to that yet.

[825] The Court: I certainly will entertain your motion if there is nothing further offered.

Mr. Rines: We will get around to it, your Honor.

The Court: I agree with you, Mr. Cass, that a better practice, having offered the exhibit and the Court having taken it into evidence over objection, on the representation of counsel, he should pursue it instead of going off to something else, but I make it a practice within reasonable limits, not to tell a lawyer how to try his law suit, but I don't think you should jump from one issue to another. It doesn't make for orderly procedure.

• • •

[860] Mr. Cass: I offer Counter-Defendant's Exhibit No. JFD 16 into evidence.

The Court: This isn't your part of the case yet.

Mr. Cass: The purpose of offering it at this time is to interrogate this witness with respect to it.

The Court: I can't help that. You can bring him in here yourself. Now you have sat through this trial. I have not permitted the introduction of exhibits by one side while some other party is engaged in presenting its case.

Do you withdraw the offer?

Mr. Cass: I withdraw that offer, your Honor.

• • •

[875] Q. Prior to the making of the alleged invention set forth in Defendant's Exhibit 26, what were traditional methods of maintaining the position of a transmission line as it was connected to the feed point of an antenna? A. It was usually held in place by insulators.

Q. Where were these insulators mounted? A. The insulators were mounted along the supporting boom.

Q. Did these insulators provide a rigid support for the transmission line? A. Yes.

• • •

[902] *By Mr. Berliner:*

• • •

Q. Is it your position that any other models in the Ranger line are covered by Claim 5 of Defendant's Exhibit 26? A. Yes.

Q. Does that include the Ranger 3? A. Yes.

• • •

[905] Q. Is it correct to say that since the time Jerry Balash left Blonder-Tongue, there have been four additional employees who left Blonder-Tongue and went to work for JFD? A. To the best of my knowledge.

Q. Since Jerry Balash left the employ of Blonder-Tongue, how many other employees have left the employ of Blonder-Tongue? A. Possibly a hundred.

• • •

[935] Q. Would you agree that the word "remote" is indefinite as applied to the device shown in Defendant's Exhibit 27-A? A. Yes.

• • •

[941] Q. What is the shortest wavelength in that frequency range? A. 890 megahz.

Q. What wavelengths, not what frequency. A. I have to convert it. I don't commonly think in terms of wavelengths.

I have to divide it into 300 in order to come up with the answer.

Q. Please work that out. A. Well, at the risk of being reproved, it is about 33 centimeters.

Q. Converting that to inches, are we not talking about something in excess of 10 inches? A. It is in the neighborhood of 5 inches—sorry. I will have to convert it into inches in a minute.

Q. Will you please raise your voice, sir. A. I will convert it to inches. Approximately 13 inches.

Q. If the antenna of Plaintiff's Exhibit 10 [942] were to be modified by separating the booms to a distance of, say, 10 inches, would the device still function as a UHF antenna? A. It would not function in the manner in which I intended. There would be some reception of UHF, but I would consider it an inadequate device. Any piece of metal hung up in the air will receive signals. It will receive them to the extent that there is a reception.

Q. Well, would the modified antenna be commercially acceptable? A. No.

* * *

[943] Q. At what point in the separation of the booms of Exhibit 10 would you cease to be satisfied with the performance of the antenna? A. Well, it varies as you change frequency and you would have to discuss whether the overall reception of the antenna over the entire frequency band were considered usable enough. You might possibly deteriorate some of the performance at the upper end in order to gain an advantage at the lower end. I would personally like to keep the separation between those two booms to—I think that if I went as high as three inches, that would be the maximum, and at that point you start to suffer some deterioration at the upper end. There aren't many television stations there and some television manufacturers do make the decision to reduce performance and apparently the customers accept it.

Q. In fact, is the spacing between the booms in Plaintiff's Exhibit 10 less than the spacing between dipole elements? A. For most of the antenna, yes, for most of it, not all of it.

[944] Q. Do you know what the spacing is between the first two shortest dipole elements? A. I don't remember it.

Q. But you will agree that is less than the spacing between the booms? A. I think it is almost the same but I am not sure. It is very closely similar to the spacing between the booms. It is about the upper limit of what I care to go in separation and still maintain sufficient performance.

Q. Is there any appreciable deterioration of performance when the boom spacing exceeds the distance between the dipole elements? A. No.

Q. Then is it correct to say that the particular spacing that you chose in Plaintiff's Exhibit 10 is not something that everyone else would choose in order to obtain a commercially acceptable antenna? A. I think all designers have different objectives in mind. This is the one I chose with my objectives in mind. Other designers may choose to change their spacing as they determine is satisfactory.

[945] Q. But there would be no violent objection to increasing the boom spacing so that it slightly exceeded the spacing between dipole elements, is that correct? A. As I explained, it would deteriorate somewhat the performance at the upper end but there would be no real objection to it, no.

* * *

[961] Q. All right.

Well, let me ask you sir, of the structural elements that are positively recited in claim 5 of Defendant's Exhibit 26, as of the time of the alleged invention of that structure, which of those elements so recited in that claim were new and which of those mechanical elements were old? A. All the mechanical elements were old.

* * *

[981] *By Mr. Cass*:

Q. I now direct my question specifically to Count II of the counterclaim and that is the antitrust charge. A. May I have a copy of that?

Mr. Cass: Would you give the witness a copy of Count II, please?

(Document handed to the witness.)

The Court: I might say that I don't know whose handiwork this document is, this amended answer—counterclaim, but somebody got lazy and Count II is entitled "Antitrust," and then it goes on to say, "8 and 9. Counterclaim realleges Paragraphs 8 and 9 of the counterclaim."

When an amended pleading is filed, that is the pleading. The Court should not be compelled to go back to some document that has been superseded by an amended pleading. Now I have the amended pleading, the counterclaim here, and I can't tell from that document what the defendant and counterclaimant asserts were violation of the antitrust laws.

Isn't that right, sir?

[982] Mr. Phillips: I agree, your Honor.

The Court: These cases are difficult enough without complying with our local rules. If you will look at our local rules with respect to pleading, you will find that point is covered. It just makes it difficult with all of the documents that are filed here to have to go through the papers to find the original counterclaim when we are dealing with an amended counterclaim.

*Testimony of Isaac S. Blonder*

*By Mr. Cass:*

Q. Mr. Blonder, you will agree that the charges of antitrust violation are very serious indeed, will you not? A. Yes.

Q. Specifically what market area were these antitrust violations committed by JFD in? A. To my knowledge in all market areas that we are concerned with.

Q. And what market areas are those, sir? A. The United States.

Q. And what were the products that were involved in those market areas?

Mr. Cass: Your Honor, I might point out to the Court that in answer to my question the witness [983] is leafing through some documents and I don't know whether I am getting the answer of the witness free of any—

The Court: Oh, the witness will not be permitted to examine documents to answer a question. If he cannot answer the question, he may say he cannot answer it and I will excuse him from answering it.

The Witness: I can answer it.

Commercial TV antennas.

*By Mr. Cass:*

Q. Any other products that are involved in these antitrust violations which you charge? A. Not in the ones we charge.

Q. So that the antitrust acts which you charge JFD and the Foundation with relate to a United States market pertaining to commercial television antennas, is that correct? A. Yes.

Q. In connection with the television antennas, commercial television antennas that you have mentioned, does that

include any and all television antennas that are commercially on the market in the United States? A. No.

[984] Q. Then to what antenna products are your charges limited? A. To the ones JFD stated to our distributors that we were manufacturing.

[985] Mr. Cass: Your Honor, I move to strike that.

The Court: It may go out as not being responsive to the question.

The Witness: Will you repeat the question, please?

The Court: Read the question.

(The reporter read the question.)

*By the Witness*:

A. Antennas.

*By Mr. Cass*:

Q. Are there any particular type or types of antennas to which your charges are limited? A. A class of antennas known as log-periodic antennas.

Q. Now, for the edification of the Court, are there any other types of television antennas on the market in the United States? A. Yes.

Q. What types are they? A. Usually a modified form of Yagi antennas.

Q. Any others? A. There are conical antennas.

Q. Any others? I would like you to name all of the different types of commercial antennas. [986] A. Parabolic, rhombic, rabbit ears or ordinary folded dipoles, wire dipoles.

Q. Any others that you know of? A. There could be others. I think I have named the most important ones.

Q. How about bow-tie antennas? A. I named the bow-tie. I said dipole antenna.

Q. It is a dipole antenna. A. Yes.

Q. These antennas that you have mentioned, in addition to the log-periodic type of antenna, are these commercial TV receiving antennas, sir? A. Yes.

Q. Are these antennas, in additon to the ones you referred to as log-periodic type antennas, in competition in the United States? A. Yes.

Q. And yet it is the position of the defendant that the antitrust violations complained of are limited only to the log-periodic type antenna, is that correct? A. Yes.

Q. Do you know, Mr. Blonder, whether the [987] activities which you charge JFD and the Foundation with, as having damaged the defendant, also damaged any of the other competitors in the United States of Blonder-Tongue and JFD? A. No.

Q. Prior to the institution of the counterclaim, sir, were any surveys or investigations made for the period 1963 to date to obtain sales figures for commercial TV antennas of the log-periodic type in the United States? A. Made by whom?

Q. By Blonder-Tongue. A. Blonder-Tongue continuously makes surveys, market surveys, for all its products.

Mr. Cass: Your Honor, I move to strike that answer and ask the witness to answer the specific question.

The Court: The answer may go out as not being responsive to the question. Please read the question to the witness.

(The question was read.)

*By the Witness*:

A. Yes; they were made by Blonder-Tongue.

[988] Q. And where are those reports or investiga-

tions, sir? A. They should be on file in our Sales Department.

Q. They should be. A. Yes.

Q. Did you have any role in the obtaining of the reports about which you just testified? A. As chairman of the company, I request the market surveys be made. I did not personally make any survey?

Q. When were those surveys made? A. Continuously.

Q. Well, would you be more specific as to time, sir? 1963? Would that— A. No, we always collect data continuously on sales of all products that we are interested in, and these are continuously accumulated and reported on, virtually every two weeks.

Q. All right. Now, you testify at this time that these are investigations and reports that you have accumulated as in the normal course of business of the defendant, is that correct? A. Yes.

[989] Q. I ask you, did you make any particular surveys or investigations for the purpose of substantiating the counterclaim 2—that is, count 2 of the counterclaim—as to antitrust? A. No.

Q. Isn't it a fact, sir, that at this particular time defendant has no knowledge at all as to whether or not the alleged activities complained of in this counterclaim had any effect on any other competitors in this field? A. I only have hearsay comments in that regard but not personally.

Q. And that is your answer on behalf of the defendant in this case? A. Yes.

Q. Did you make any attempt to survey your competitors to find out what these activities may have done to them? A. I believe such attempts were made. I didn't personally make them.

* * *

*Deposition of Jerome N. Balash*

[1002] IN THE

UNITED STATES DISTRICT COURT

• • (Caption—66-C-567) • •

Before:

JULIUS J. HOFFMAN, *Judge.*

Friday, January 12, 1968,
2:00 o'clock p.m.

• • •

[1030] Mr. Phillips: I shall. First is the deposition of Jerome N. Balash taken by the defendant at the offices of Ostrolenk, Faber, Gerb & Soffen on February 17, 1967, 2:10 p.m.

• • •

[1036] Mr. Berliner: Skipping to page 36, examination by Mr. Berliner:

"Q. Mr. Balash, what were the circumstances under which you left the employ of Blonder-Tongue and went to work for JFD? A. I resigned from one company and went to work for the other.

[1037] Q. Did JFD approach you or did you approach JFD? A. If you want the whole history, I learned that JFD had an opening in their sales department during the Parts Show in, I guess it was May, in Chicago. No, I am sorry. In San Francisco. When I got back from the Parts Show, I contacted them and asked them if it was true that there was some opening, and they said they might have something and asked me to come over and talk to them. I did and found out that one of their men had given notice and was leaving the company, and there would probably be an opening in their Sales Department.

Q. When did you make this decision to leave Blonder-Tongue and go to JFD? A. During the vacation period of last year, which was the first two weeks in July.

Q. How soon thereafter did you advise Blonder-Tongue you were leaving? A. The first day I came back from vacation."

• • •

[1038] Mr. Phillips: With the Court's permission, the deposition of Jerome I. Cohn, taken on February 17, 1967—if your Honor please, the entire deposition in this case will be offered, and we can give the transcript to the reporter, and she can spread it of record and avoid the necessity for reading portions in open court.

• • •

[1039] "*Examination by Mr. Berliner*:

• • •

[1040] Q. Prior to the time when Jerry Balash left Blonder-Tongue, had you and he had any conversations during which Balash expressed dissatisfaction with his position at Blonder-Tongue? A. Yes.

Q. Do you recall any specific complaints that he made? A. From the day I met Jerry he complained [1041] but specifically it was in the nature of dissatisfaction with either communications or the tools with which he had to operate. This wasn't specific in any one particular area but just generally.

• • •

[1047] Mr. Phillips: From the deposition of Harry [1048] Gilbert, taken on February 7, 1967, at the offices of Ostrolenk, Faber, Gerb & Soffen at 10:00 o'clock a.m., I would like to read certain excerpts.

• • •

[1048] "Q. Do you recall the names of your field men who have made reports to you that [1049] JFD had threatened your customers with suit? A. Jerry Balash."

• • •

[1050] "Q. Have you received any reports that JFD has refused to sell JFD antennas unless the customers also buy auxiliary equipment, such as converters or amplifiers? A. Yes. To my recollection, not in writing. I don't recall a written report on it, but we have had much discussion on it.

Q. Who was present at these discussions? A. It would be Richard Helhoski and Jerry Balash. At this point I can't be sure, but perhaps John Linneman in a subsequent period.

Q. Do you recall seeing any written documents relating to the subject? A. No.

Q. Have you ever discussed this subject with any Blonder-Tongue customers or potential customers? A. Personally, no.

Q. Have you ever received any reports that JFD salesmen had refused to sell JFD antennas to Blonder-Tongue customers unless they stopped buying Blonder-Tongue products? [1051] A. I have heard talk, but again I don't recall any written report.

Q. You do not recall seeing any written report? A. No. I will check my files with this specific question in mind, but I don't recall.

Q. Do you recall the names of any Blonder-Tongue customers that were involved in such allegations? A. No.

Q. Do you recall the names of any Blonder-Tongue customers or potential customers who are involved in any allegations concerning JFD's requirement that they would not sell antennas unless other products of JFD were also purchased by the customer? A. I would be guessing at this point. No. There are names that I know of JFD accounts that we have had contact with, but I can't be sure in response to your specific question."

Skipping down to line 24 on page 11:

"Q. Do you know of any instances where [1052] JFD sought to induce Blonder-Tongue customers to drop the Blonder-Tongue line by offering special promotions? A. Personally, no."

Mr. Phillips: Continuing on page 12, your Honor, at line 3, I believe:

"Q. Have you received any reports on such activities on the part of JFD? A. I don't recall any written reports on it.

Q. How about oral reports? A. Oral reports I have heard.

Q. Who gave you these reports? A. Jerry Balash."

Dropping down to line 18:

"Q. Do you have any records to indicate the identity of the customers concerned? A. The records would all be either the reports that we have on file or the files that Jerry Balash had kept, copies that he had, and they are no longer on the premises.

Q. Do you know who has those files? [1053] A. They disappeared the week he left."

* * *

[1056] "Q. What was Jerry Balash's position with Blonder-Tongue? A. From beginning to end?

Q. Well, let us say at the beginning of 1966 until the end. A. At the beginning of 1966 Jerry Balash was the distributor of products, product manager.

Q. Did his position change from the beginning of 1966 until the time when he terminated employment? A. It did.

Q. Be more specific. [1057] A. On approximately May 9 we put a new man on to handle the antenna portion of the distributor products in an attempt to put a greater emphasis on the antennas and to give Jerry Balash more time

and adequate time to handle other devices, Blonder-Tongue boosters and converters.

Q. Is it then accurate to say that after the new man was hired in May of 1966 that Mr. Balash's responsibility with respect to Blonder-Tongue's antennas was just nominal, if at all? A. Nominal is the word.

Q. Was Jerry Balash the organizer of Blonder-Tongue's complete antenna business? I am paraphrasing from the counterclaim. A. No.

Q. Who was the organizer of Blonder-Tongue's antenna business? A. It would be Richard Helhoski.

Q. Was there ever a time when Mr. Balash was the sole and key executive in Blonder-Tongue's antenna business. A. Yes.

[1058] Q. When was that time? A. When we introduced our Ranger series of antennas.

Q. When was that? A. To the best of my recollection somewhere around August through October, 1965. Somewhere in that area.

Q. At that time was he the sole and key executive or the sole executive? Was he ever the sole executive? A. No, not the sole executive. He was the product manager in charge of antennas but he reported to a Director of Marketing and he couldn't make the decisions himself.

Q. Prior to the time when Mr. Balash advised Blonder-Tongue that he was terminating employment did he ever express any dissatisfaction to you with his position at Blonder-Tongue? A. Frequently.

Q. Did he ever advise that he was looking around for another position? A. From the very earliest part of his career with Blonder-Tongue this was a repetitive refrain."

[1059] Mr. Phillips: Dropping down to the last line of Page 20:

"Q. In your earlier testimony I believe you indicated that certain files disappeared about the time Jerry Balash left? A. That's right.

Q. Can you be specific as to what those files were? A. We maintain at Blonder-Tongue letters and books which are chronological carbon copies of all correspondence of key executives and the letter books were not there some time during the week following Jerry Balash's departure. His successor couldn't locate them.

Also the files in the desk drawer, in the four-drawer file in the product manager's area had a number of empty folders and one of the major reports, a six-month IBM report for the six months ending April 30, 1966 giving a breakdown by customer, address and product line, was not available and the Weingard catalog and price sheets, we had two copies in the product manager's area, the week following his departure, one of those copies had disappeared.

[1060] Q. You say 'the week following.' A. He left, I believe, on the 29th and in the next succeeding few days when the area was reviewed to see what was there these things were missing.

Q. Have any of these documents shown up since? A. No.

Q. You said the letter books contain carbon copies of correspondence of key executives:

Did they just include letters sent from Blonder-Tongue or the correspondence received from customers or from third parties? A. The correspondence from the one executive to all parties inside Blonder-Tongue and all third parties outside Blonder-Tongue.

It is a complete file of any memorandum he dictated during his stay at Blonder-Tongue."

Dropping down to Line 21:

"Q. When you say letter books were missing I get the impression that there are many letter books, a different one for each executive? A. There is a different one for each [1061] executive and each executive may generate in his period with us.

Q. Specifically what letter books were missing? A. The Jerry Balash letter books and approximately three or four of them.

Q. Were the letter books of any other executive missing? A. Not to my knowledge."

Mr. Berliner: Line 16 of Page 23:

"Q. Did anyone but Mr. Balash have access to the product manager's copy? A. I would say yes.

Q. Did anyone but Mr. Balash have access to the letter books including Mr. Balash's letter books? A. Yes, the same as the books over here on the shelf."

* * *

[1063] Mr. Phillips: This is the deposition of [1064] Richard B. Helhoski taken at the offices of Ostrolenk, Faber, Gerb & Soffen on February 17, 1967 at 9:30 a.m.

* * *

"Q. Please state your name and address for the record, please. A. Richard B. Helhoski, 8 Arborway, Morristown, New Jersey.

Q. Who is your employer and in what capacity are you employed? A. Blonder-Tongue Laboratories, Inc. I have just received a change from the capacity of Director of Marketing to General Manager, Special Accounts.

* * *

[1067] Q. Did any of these distributors say that JFD had threatened not to supply further antennas if these distributors took on the Blonder-Tongue line? A. No direct statement; however, implied.

Q. Which one of these distributors implied that JFD would not sell to them unless [1068] they dropped the

Blonder-Tongue line or did not carry the Blonder-Tongue line? A. I have to say, because it is implied, the implications that were by at least one account, what was stated was that we should straighten out our problems with log periodic antenna and the threats that were impending because the distributors themselves—and this is where the implication comes—"We don't want to be involved in this type of situation"—meaning there are other manufacturers to buy from.

This, of course, was stated by Allied Radio as one of the major concerns.

Q. And from that you drew the implication that JFD would not sell to these distributors if they continued to handle these Blonder-Tongue lines? A. I drew no conclusion because I don't care what JFD does.

I am interested only what customers were interested in buying of our products and therefore have to give them whatever is needed to satisfy them to keep buying within our judgment and means, of course.

Q. Did you receive any reports from [1069] Mr. Balash with the direct statement that a distributor had been told by JFD that JFD would not sell TV antennas to this distributor if the distributor sold Blonder-Tongue's lines? A. I can only say it is a long time since the reports that were addressed to me and Mr. Gilbert were written by Mr. Balash. However, I assume these are of record and I can't make an answer.

The reports are written.

Q. Other than Mr. Balash's were there any other written reports given to you by any other employees of Blonder-Tongue or anyone else? A. If my memory serves me, I don't know of any, which does not mean there wasn't any. I just don't recall."

[1070] Page 9:

"Q. Have you received any reports to the effect that JFD would not sell TV antennas to any customers who did

not also purchase JFD's line of UHF converters and signal amplifiers? A. Only by implication. No customer made any direct statement, as I answered before.

Q. From what statement do you draw the implication? A. My earlier statement relative to Allied Radio.

Q. Have you received reports or conferred with Mort Leslie concerning JFD's tactics in selling TV antennas? A. I, of course, have had discussions with Mort Leslie. However, to my recollection no discussions relative to their tactics, and of course I find that hard to answer. I don't know what it implies.

Q. Did Mr. Leslie ever tell you that JFD had a policy that it would not sell to [1071] distributors who carried Blonder-Tongue products? A. No, he did not.

Q. Did he ever say that JFD would not sell TV antennas to a customer unless that customer also carried UHF converters and signal amplifiers sold by JFD? A. We are back to implications again. Such statements were not made direct. However, this is known in their statement or in the world of selling, the pressure of selling, pressing the customer to buy the entire line."

• • •

[1072] "Q. Do you know if Mr. Balash, upon leaving Blonder-Tongue, took any Blonder-Tongue records with him? A. I do not know.

Q. Do you have any reason to believe that he did? A. Let me go back. There is an apparent record missing.

Q. What record is that? A. The sales report figures and list of our accounts which is an IBM runoff of what they purchased. This report is missing. I am not going to accuse Jerry Balash. I don't mean to infer that. It is missing. That is a fact coincident with Jerry's leaving."

• • •

*Deposition of Robert F. Heslin*

[1073] "Q. Was Jerry Balash the organizer of Blonder-Tongue's complete antenna business? A. Yes, from the marketing standpoint. He did not organize the production, and he didn't organize the design engineering. He [1074] did organize the sales effort, the method of selling it, the approach."

* * *

[1091] Mr. Allen: I just wanted to make sure that there was no need for Mr. Blonder to stay so we will excuse him.

The Court: What do you say?

Mr. Allen: Mr. Blonder, there is no reason for him being here on Monday.

Mr. Marshall: We have no need for Mr. Blonder, your Honor.

The Court: I would direct him to return only at the request of one of the parties.

Mr. Allen: I just wanted to put them on notice.

The Court: If any one of the parties does not move to direct him to return—

Mr. Marshall: On behalf of the Foundation, your Honor, we have no need for Mr. Blonder.

Mr. Cass: We have no need for him. We have identified the exhibits.

* * *

[1104] Mr. Berliner: At this point I would like to read portions of the deposition of Robert F. Heslin.

* * *

[1130] Q. Now, we notice in the article, J-10, that your sentence from Page 1 of the draft, Exhibit J-11, which merely said, 'Provisions are also included to feed it with open wire line'—we notice an additional phrase, and I will read the total thing on Page 50 of Exhibit J-10:

'The antenna can also be fed with open wire line but with a high SWR which would make it essential to use an antenna coupler at the in-put end of the line.'

Where did that essential use of the antenna coupler come from, if you know? A. Since the antenna has a basic characteristic of most antennas of reciprocity—by that I mean it can be used both as a receiving and a transmission antenna—the high-standing wave ratio present at the feed point would be detrimental to a transmitter unless one were to employ an antenna coupling device to match [1131] out this standing wave ratio.

Q. First of all, is this your language in the article about the essential requirement of an antenna coupler at the in-put end? A. Yes, it is.

Q. Why, did you add it?—Mr. Heslin, I have no desire to trap you. Perhaps you might look at all the drafts you have shown us and see if when and if you ever added such language. A. Well, let me say this: Obviously it is not in any of my original drafts. I recall discussions about this feeder and it could very well be that this was added by Mr. Campbell at QST.

Q. By 'QST' you mean the magazine in which J-10 appeared? A. Yes.

Q. Who is Mr. Campbell? A. Mr. Campbell is a member of the technical staff of the American Radio Relay League, publishers of QST.

Q. Do you characterize him as an antenna expert? [1132] A. I do not know Mr. Campbell personally and going back over the years and the various articles that he has been involved with, I would say that he is not particularly an antenna specialist. I would say he is a jack-of-all-trades.

Q. Would you say he is as competent as you in the field of antenna, or more competent? A. I can't answer that.

Q. Do you agree with his statement that an essential element would be an antenna coupler at the in-put end of the line if one were to feed the antenna with an open wire line? [1133] A. If this particular antenna in its present

form were to be used as a transmitting antenna and fed with open wire line, let me say of 300 ohms characteristic impedance, then the answer is yes.

Q. By reciprocity what is the difference if the antenna is used as a section? A. Once again, are you talking about feeding with open wire line?

Q. Yes. Is this also a true statement? A. That is true, yes.

Q. Would you be surprised to know that this problem of feeding the type of antenna under discussion with a 300 ohm parallel line has been successfully effected without the use of such antenna coupler? A. Well, I realize that this is true, that there are antennas in existence that are doing this. I have not been aware of it. I have not been in the antenna field for several years. I would be interested in knowing the details behind it.

Q. Would it be fair then to say that it certainly was not obvious to you or to Mr. Campbell, apparently, that such an antenna could be fed [1134] with a parallel wire line without an antenna coupler at the time you wrote the article? A. This antenna.

Q. Yes, sir. A. Yes, some means for matching purposes.

Q. And if it could be done without an antenna coupler, this would be a surprise to you at that time? A. At that time, yes.

* * *

[1180] Edward Finkel, called as a witness by the counterclaim defendant JFD herein, having been first duly sworn, was examined and testified as follows:

* * *

[1192] Please examine Counter-defendant's Exhibit No. JFD 21 and tell us, if you can, what the documents of this exhibit are. [1193] A. These are original copies of progress reports sent to me weekly from the laboratory in Champaign on the progress of work done at the laboratory that preceding week.

Q. What type of work is done at the laboratory? A. Well, we are constantly researching the development of improved antenna reception and the laboratory has been given assignments under project numbers to work on that effort and from time to time, as I say, weekly it was their responsibility to send me reports of the work that had been previously done.

Q. Do you know if there was any connection between the antenna illustrated in Defendant's Exhibit 27-A and the progress reports of Exhibit JFD 21? A. Well, that is an enlargement of the twin boom design that the laboratory had been working on since early 1963.

Q. Do you find references to twin boom designs in Exhibit JFD 21? A. Yes, I do.

I am looking at a report of January 25th talking of an antenna for UHF which mentions [1194] epoxying to booms.

I am looking at a report of February 8th, Reference No. 3, in which construction and placing of plastic spacer bars between booms covers the twin boom investigation.

I am looking at a report of March 2, 1963 where again reference is made to Project No. 4 discussing the problems on VSWR measurements caused by the spacers on the twin 150 ohm booms. The second page of that report discusses the separation of the booms to achieve certain impedances indicating the type of problem they were having of designing the antennas, and so on.

A report of March 9th again discusses using twin boom construction which we constructed for the University of Illinois Foundation in 1961. It is a statement by Paul Mayes to the effect that he had used this antenna on his home for several months and that was the basis of the statements about the TV reception in the original Microwave Journal article.

A report of April 27th again discusses a combination VU antenna project No. 9 which identified a twin boom research program, and so on.

[1195] Progress Report of May 25, 1963 discusses a VU LPV-18 single boom and twin boom scale models clearly delineating single boom versus twin boom as two areas of investigation.

June 1, 1963, Project No. 9 discusses again VU LPV-18 twin construction, time sixteen hours. "This is a special low impedance transformer for twin boom antennas", and so on.

Q. Where did these reports come from? A. These reports came from the JFD Research and Development Laboratories directly to me at my office in New York.

Q. When did these reports come to you? A. They usually came on the Monday or Tuesday following the Saturday on which the report was typed up covering the previous week's work.

Q. Are these reports kept by you in the regular course of your business? A. Yes, they are.

• • •

[1197] Q. Have you ever solicited Blonder-Tongue employees to leave the employ of Blonder-Tongue and go to work for JFD? A. No, I have not.

Q. To your knowledge has anyone at JFD ever solicited a Blonder-Tongue employee to leave the employ of Blonder-Tongue and go to work for JFD? A. No, we have not.

Q. Is it a policy of JFD to solicit employees of Blonder-

Tongue asking them to leave Blonder-Tongue and come to work for JFD? A. No, it is not.

* * *

[1208] Paul Eugene Mayes, called as a witness by and on behalf of the counterclaim, defendant JFD, having been previously duly sworn, resumed the stand, was examined and testified further as follows:

* * *

Q. Professor Mayes, I ask you if you can [1209] identify Exhibit JFD 13?

* * *

A. Yes.

*By Mr. Berliner*:

Q. What is it? A. This is an antenna which was constructed for the purpose of doing experimental tests on log-periodic resonant V arrays for the reception of television signals.

Q. Who constructed this antenna and when was it constructed? A. It was constructed by technicians and members of the shop personnel at the University of Illinois.

Q. When was this done? A. It was done in 1961. I believe it was completed sometime in the summer of 1961.

Q. Has this antenna been operated? [1210] A. Yes, it has.

Q. What manner has this operation taken? A. After the experimental tests were completed, this antenna was mounted on a tower at my home and was used as a television receiving antenna connected actually to a television receiver for several months.

* * *

[1224] Q. Are you familiar with the physical embodiments of the antenna illustrated in Defendant's Exhibit 27-A? A. Yes, I am.

Q. How did you become familiar with such antennas? A. I participated in the design work for the [1225] antennas, which are represented here by the drawing Exhibit 27-A.

Q. When did you perform this design work? A. In 1963.

Q. Do you recall which portion of the year? A. The design work began in the spring, in April or May of 1963.

Q. Where was this design work performed? A. At the JFD Research and Development Laboratories in Champaign, Illinois.

* * *

[1225] Q. At the time the antenna of Exhibit JFD 13 was constructed did those skilled in the antenna art know that it was necessary to increase boom spacing of a twin boom log-periodic antenna structure, in order to increase its characteristic impedance? A. Yes.

* * *

[1259] Q. In Defendant's Exhibit 26, if the transmission line TL bypasses the strain reliefs 2′ and 4′ and is run directly from terminals 1″ and 1‴ to the stand off on mast M, will the performance of the antenna of Fig. 1 be adversely affected? A. No.

## Order Setting Sequence of Proof at Trial

IN THE

UNITED STATES DISTRICT COURT

FOR THE NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

---

Civil Action No. 66 C 567

---

THE UNIVERSITY OF ILLINOIS FOUNDATION,
*Plaintiff and Counterclaim Defendant,*

v.

BLONDER-TONGUE LABORATORIES, INC.,
*Defendant and Counterclaimant,*

v.

JFD ELECTRONICS CORPORATION,
*Counterclaim Defendant.*

---

This matter having come before the Court on the motion of plaintiff and the Court having considered the same, in the interest of facilitating the conduct of the trial, IT IS HEREBY ORDERED that the order of proof at the trial will be as follows:

1. Plaintiff's proof on background of invention and infringement by defendant Blonder-Tongue of patents 3,210,767 and Re. 25,740.

2. Defendant Blonder-Tongue's proof on invalidity and non-infringement of patents 3,210,767 and Re. 25,740.

3. Rebuttal by plaintiff.

4. Defendant Blonder-Tongue's proof on the issues raised in its counterclaim:

(a) Unfair competition and anti-trust violation by counterclaim defendant JFD and plaintiff.

(b) Infringement by counterclaim defendant JFD and plaintiff of patent 3,259,904.

5. Proof by plaintiff and counterclaim defendant JFD on issues of:

(a) Unfair competition and anti-trust violation.

(b) Invalidity and non-infringement of patent 3,259,904.

6. Rebuttal by defendant Blonder-Tongue.

The above sequence shall be adhered to as far as is reasonably feasible, but it is not to be construed as requiring witnesses to make several appearances merely in order to maintain the specified order of presentation.

Entered:

/s/ JULIUS J. HOFFMAN
*United States District Court Judge*

Date: April 24, 1967

**Exhibit JFD 14**

(CHART)

(PHOTOSTAT)

(See opposite ☛ )

EXHIBIT JFD

July 5, 1966 I. S. BLONDER ETAL 3,259,904
ANTENNA HAVING COMBINED SUPPORT AND LEAD-IN
Filed Nov. 21, 1963

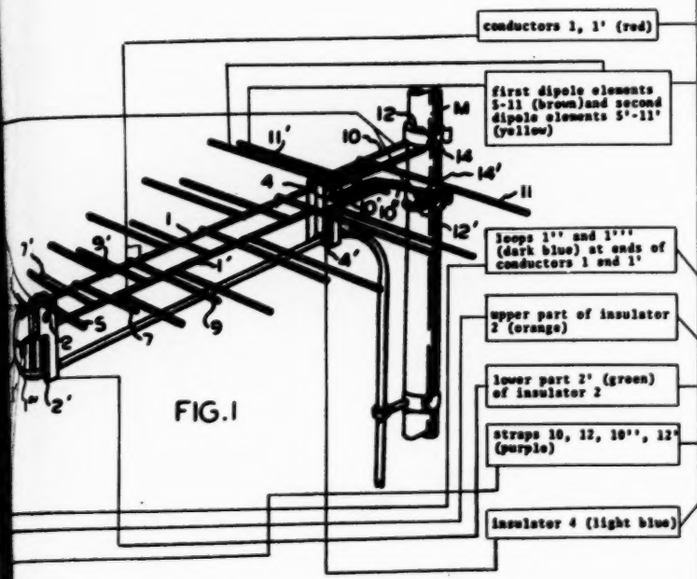
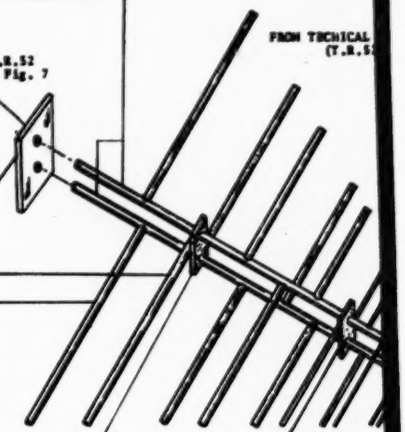



FIG. 1

| ELEMENT NO. | ANTICIPATION OF CLAIM 5 BY PRIOR ART (PARTICULARLY TECHNICAL REPORT 52) | IS ELEMENT FOUND IN T.R. 52? |
|---|---|---|
| INTRO | An antenna for operation over a predetermined frequency band, having, in combination, | YES |
| 1 | a pair or rigid longitudinal conductors held spaced a predetermined vertical distance apart in a vertical plane, | YES |
| 2 | first and second pluralities of dipole elements lying in corresponding first and second vertically spaced horizontal planes containing the respective conductors, | YES |
| 2A | the dipole elements extending from opposite sides of and transversely at an angle to each conductor at successive points therealong with dipole elements connected to one conductor extending in opposite direction to the corresponding dipole elements of the other conductor, | YES |
| 2B | the length of the dipole elements successively increasing from one end of the conductors towards the other end thereof, | YES |
| 3 | means for connecting a parallel-wire transmission line to the said one end of the conductors, | YES |
| 4 | rigid insulating means securing the said connecting means mechanically in spaced-apart relation | YES |
| 4A | and connected with means for supporting the transmission line near the said one end, | NO, BUT |
| 5 | and means for mounting the antenna at a region of the said conductors remote from the said one end, | YES |
| 6 | further rigid insulating means being provided for securing the said longitudinal conductors mechanically in rigid spaced-apart relation near the said region, | YES |
| 7 | the said vertical distance being less than the distance between the said successive points and less than the wavelengths of the said band. | YES |

CHART 1

From p.16 T.R.52 at right of Fig. 7



FROM TECHNICAL (T.R.5

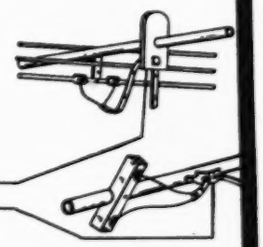
Figure 6. A log-periodic dipole antenna

"The antenna may be energized from a balanced twin wire connected at the junction of the feeder and smallest element. Alternatively, a coaxial line--" as shown in Figure 6 may be used.-- P. 18 T.R. 52.

it is obvious to provide an antenna with a strain relief member at any convenient location to support a transmission line where the latter electrically connects to an antenna as taught by the prior art as exemplified by:

-- Line Lok

-- Strain Relief on Zip Antenna



OVERSIZE PAGE – SEE NEXT FRAME
FOR REMAINDER OF PAGE

# EXHIBIT JFD 14

July 5, 1966 L. B. BLONDER ETAL 3,258,904

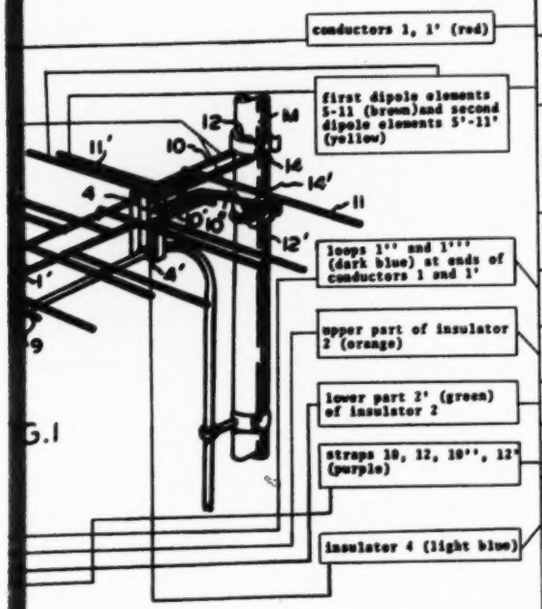
ANTENNA HAVING COMBINED SUPPORT AND LEAD-IN

Filed Nov. 21, 1963

BLONDER ETAL 3,258,904

SUPPORT AND LEAD-IN

Nov. 21, 1963




conductors 1, 1' (red)

first dipole elements 5-11 (brown)and second dipole elements 5'-11' (yellow)

loops 1'' and 1''' (dark blue) at ends of conductors 1 and 1'

upper part of insulator 2 (orange)

lower part 2' (green) of insulator 2

straps 10, 12, 10'', 12' (purple)

insulator 4 (light blue)

| ELEMENT NO. | ANTICIPATION OF CLAIM 5 BY PRIOR ART (PARTICULARLY T[E]CHNICAL REPORT 52) | IS ELEMENT FOUND IN T.R. 52? |
|---|---|---|
| INTRO | An antenna for operation over a predetermined frequency band, having, in combination, | YES |
| 1 | a pair or rigid longitudinal conductors held spaced a predetermined vertical distance apart in a vertical plane, | YES |
| 2 | first and second pluralities of dipole elements lying in corresponding first and second vertically spaced horizontal planes containing the respective conductors, | YES |
| 2A | the dipole elements extending from opposite sides of and transversely at an angle to each conductor at successive points therealong with dipole elements connected to one conductor extending in opposite direction to the corresponding dipole elements of the other conductor, | YES |
| 2B | the length of the dipole elements successively increasing from one end of the conductors towards the other end thereof, | YES |
| 3 | means for connecting a parallel-wire transmission line to the said one end of the conductors, | YES |
| 4 | rigid insulating means securing the said connecting means mechanically in spaced-apart relation | YES |
| 4A | and connected with means for supporting the transmission line near the said one end, | NO, BUT- |
| 5 | and means for mounting the antenna at a region of the said conductors remote from the said one end, | YES |
| 6 | further rigid insulating means being provided for securing the said longitudinal conductors mechanically in rigid spaced-apart relation near the said region, | YES |
| 7 | the said vertical distance being less than the distance between the said successive points and less than the wavelengths of the said band. | YES |

From p.16 T.R.52 at right of Fig. 7

FROM TECHNICAL REPORT 52 (T.R.52)

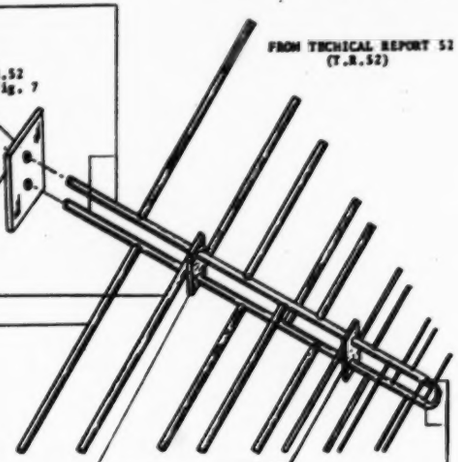


Figure 6. A log-periodic dipole antenna

"The antenna may be energized from a balanced twin wire connected at the junction of the feeder and smallest element. Alternatively, a coaxial line--" as shown in Figure 6 may be used.-- P. 18 T.R. 52.

it is obvious to provide an antenna with a strain relief member at any convenient location to support a transmission line where the latter electrically connects to an antenna as taught by the prior art as exemplified by:

-- Line Lok

-- Strain Relief on Zip Antenna

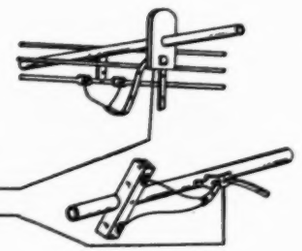


**Exhibit JFD 26C**

(Two Page Brochure)

(PHOTOSTATS)

(See opposite ☛ )

BLONDER-TONGUE

LOG-PERIODIC VHF-UHF ANTENNA

EXHIBIT JFD 26C

# COLOR RANGER-3

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
HONORABLE JUDGE HOFFMAN
DEFENDANT'S EX. NO. 41 D-26C
DOROTHY L. BRACKENBURY
OFFICIAL COURT REPORTER

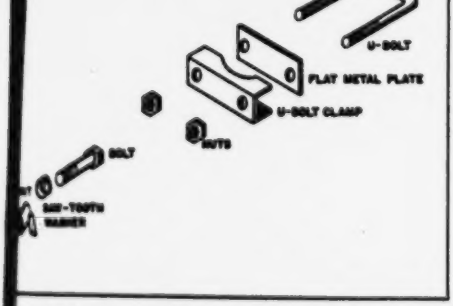
**proved design** The new Color Ranger-3 dvanced, three-element log-periodic an- esigned for optimum reception of VHF l It is especially effective for color recep- uring uniform gain and a precisely-shaped al pattern, which aids in eliminating The Color Ranger's mechanical and elec- sign incorporates the very latest develop- antenna engineering. The Ranger-3 utili- -boom construction, with its superior elec- haracteristics and mechanical rigidity. Self- , snap-out elements ensure correct ing, and are reinforced at critical points. uminum construction provides excellent protection, assuring long, trouble-free

**HF at any time** By simply turning four bolts, nder-Tongue U-Ranger antenna, designed tion as an integral part of the Ranger-3, added for UHF reception. No antenna s or separate leads to the set are required.

**the very highest standards** Every unit oes a comprehensive inspection before ng the Blonder-Tongue insignia. In this e strive to maintain the quality and reliabil- which the Blonder-Tongue name has been mous for over 15 years.

**BLY AND INSTALLATION**

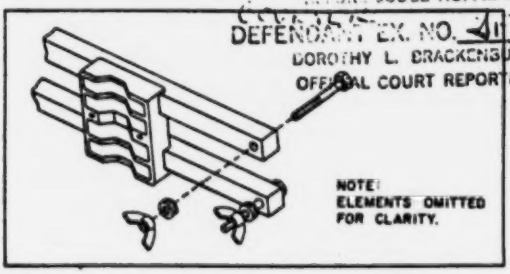
s hardware is packed with the antenna:



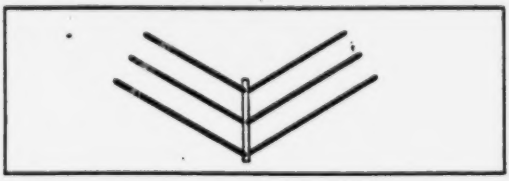

addition, you will require a mast-mounted and-off.

you plan to add UHF to the Color Ranger ntenna now, proceed to the beginning of the -Ranger instructions. If not, proceed as llows:

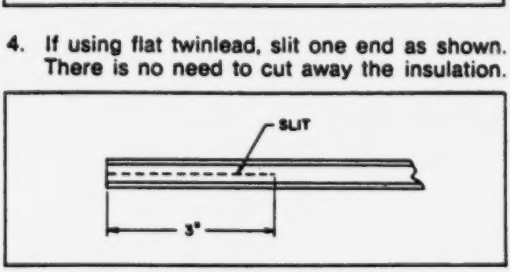
nsert bolts in holes at end of boom. Add saw- oth washer and wing nut, but don't tighten nut fully.



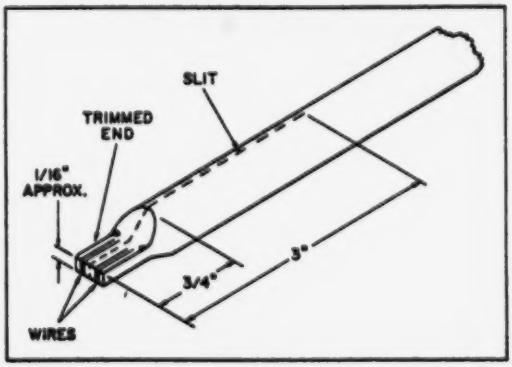

3. Take antenna to the place where you will mount it. Holding antenna elements near swivel joints to prevent bending, swing them out until they click and lock into place. The antenna will look like this.



4. If using flat twinlead, slit one end as shown. There is no need to cut away the insulation.




If using tubular or encapsulated foam twinlead (this is the preferred type of cable, especially for installation with UHF), taper and slit it as shown. There is no need to bare the wires.

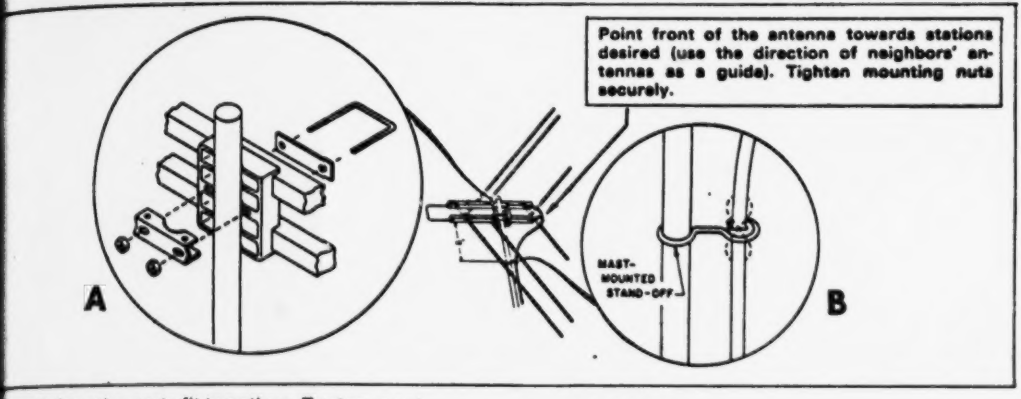


using coaxial cable, a matching transformer is required. To connect antenna terminals and 300-ohm terminals of transformer, use a short length of either foam (preferred) or flat twinlead. Follow transformer instructions for connection of coaxial cable.

**NOTE**

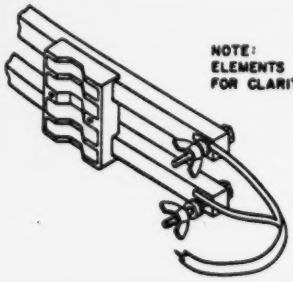
If adding or planning to add UHF, be sure matching transformer is a UHF/VHF type, such as Blonder-Tongue Model MT-283.

5. Fasten antenna to mast, as shown. "A" shows



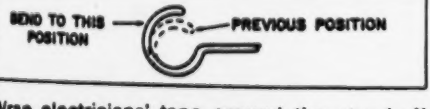

exactly how the parts fit together. Fasten mast-mounted stand-off about 18" below antenna, as shown.

Slip slit end of twinlead through mast-mounted stand-off (as shown), placing half the cable under each saw-tooth washer. Tighten wing nuts securely so that saw-tooth washers penetrate insulation, making contact with the wires inside. Excessive pressure is not required. (Fasten cable to wing bolts of U-Ranger, if used.)




**NOTE**

Some stand-offs will not readily accept encapsulated cable. If stand-off opening is too small, it may be enlarged with a file, or you may bend the metal portion of the stand-off as shown below inserting the cable.




Wrap electricians' tape around the stand-off as indicated by dotted lines in "B" (above). This maintains correct cable placement.

## ACCESSORIES

Blonder-Tongue manufactures a complete line of color-approved home distribution equipment, including antennas, signal amplifiers, matching transformers for TV and FM, and UHF converters. Below is a partial list.

| | |
|---|---|
| **U-Ranger** | UHF add-on antenna for use with Blonder-Tongue Color Ranger antennas. |
| **U/Vamp-2** | mast-mounted two-transistor UHF/VHF signal amplifier. |
| **Vamp-2** | mast-mounted two-transistor VHF signal amplifier. |
| **V/U-All 2** | indoor, two-transistor UHF/VHF single amplifier. |
| **MT-283** | UHF/VHF/FM transformer for matching antenna to coaxial downlead, and coax to set. |
| **Cablematch U/V** | indoor UHF/VHF/FM transformer for matching coax to set input. |
| **TF-331 U/V** | indoor, flush-mounted UHF/VHF/FM feed-through plate. |
| **A-102 U/V** | UHF/VHF/FM two-set coupler. |
| **A-104 U/V** | UHF/VHF/FM four-set coupler. |
| **A-107** | UHF/VHF coupler-splitter. |
| **BTX-11A** | transistor UHF converter for weak-signal areas. |
| **BTX-99A** | transistor UHF converter for strong- and medium-strength signals. |
| **BTD-44** | tunnel-diode, cordless UHF converter for strong-signal areas. |

See your dealer or distributor for further information on these products, as well as specific recommendations to meet the particular requirements of any installation.